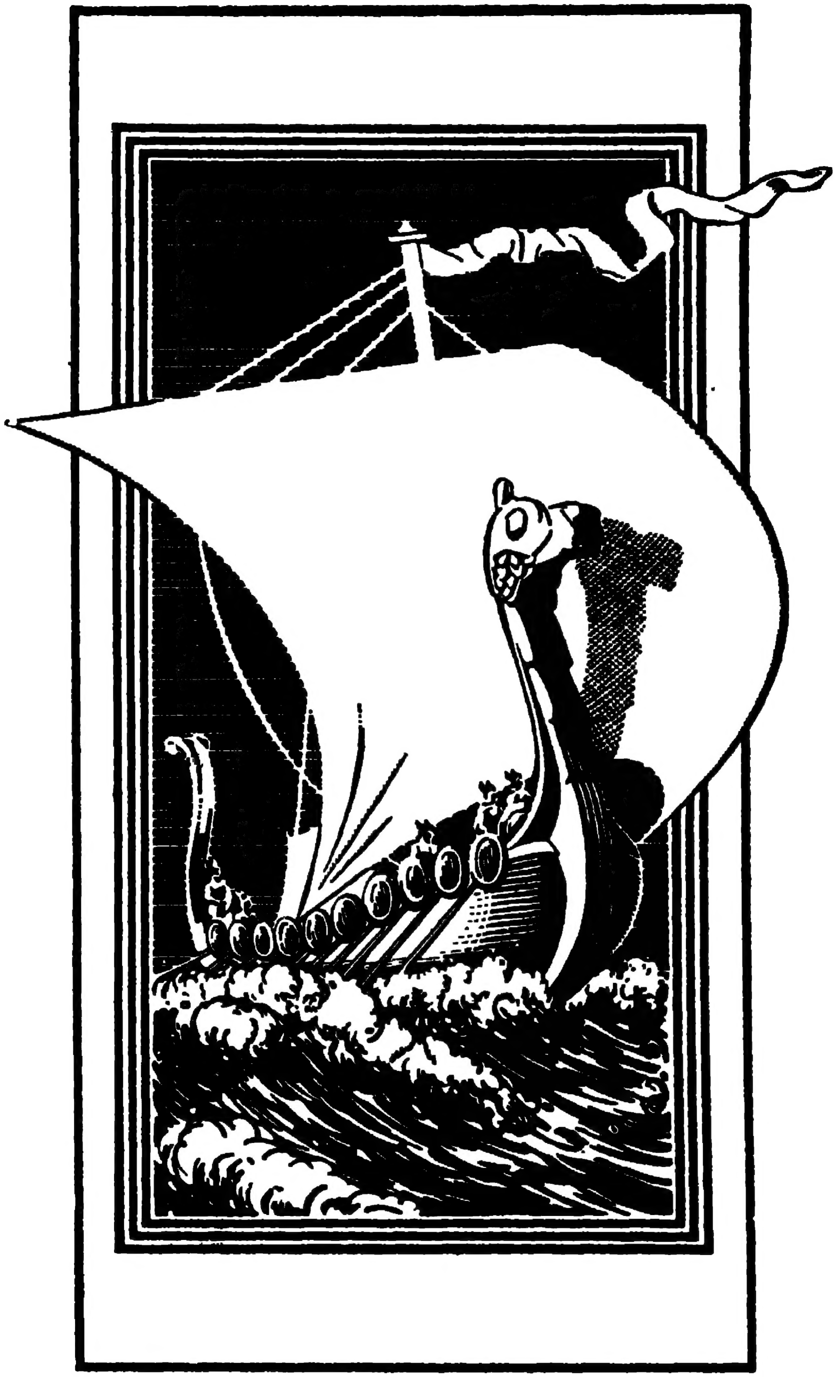
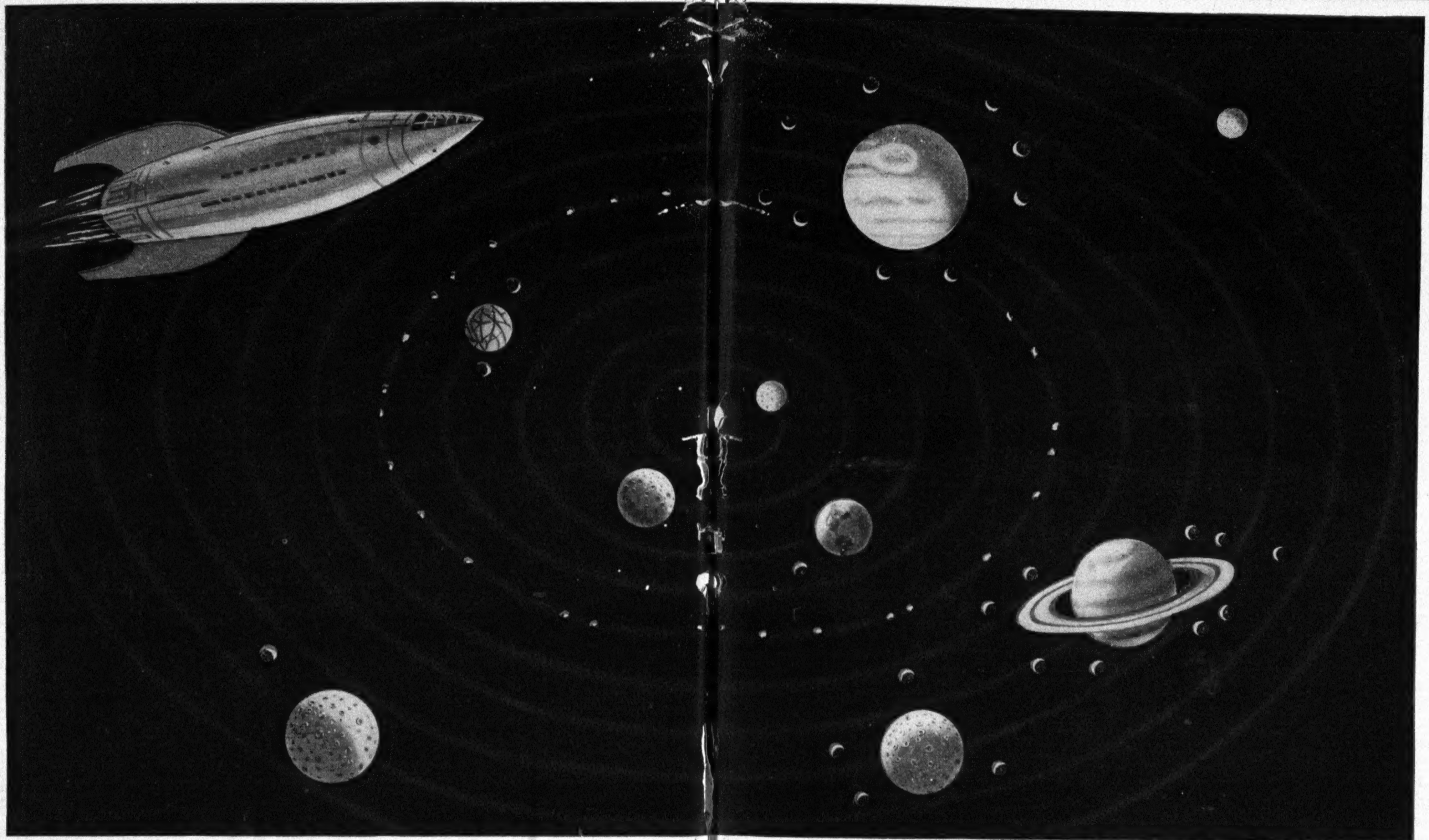
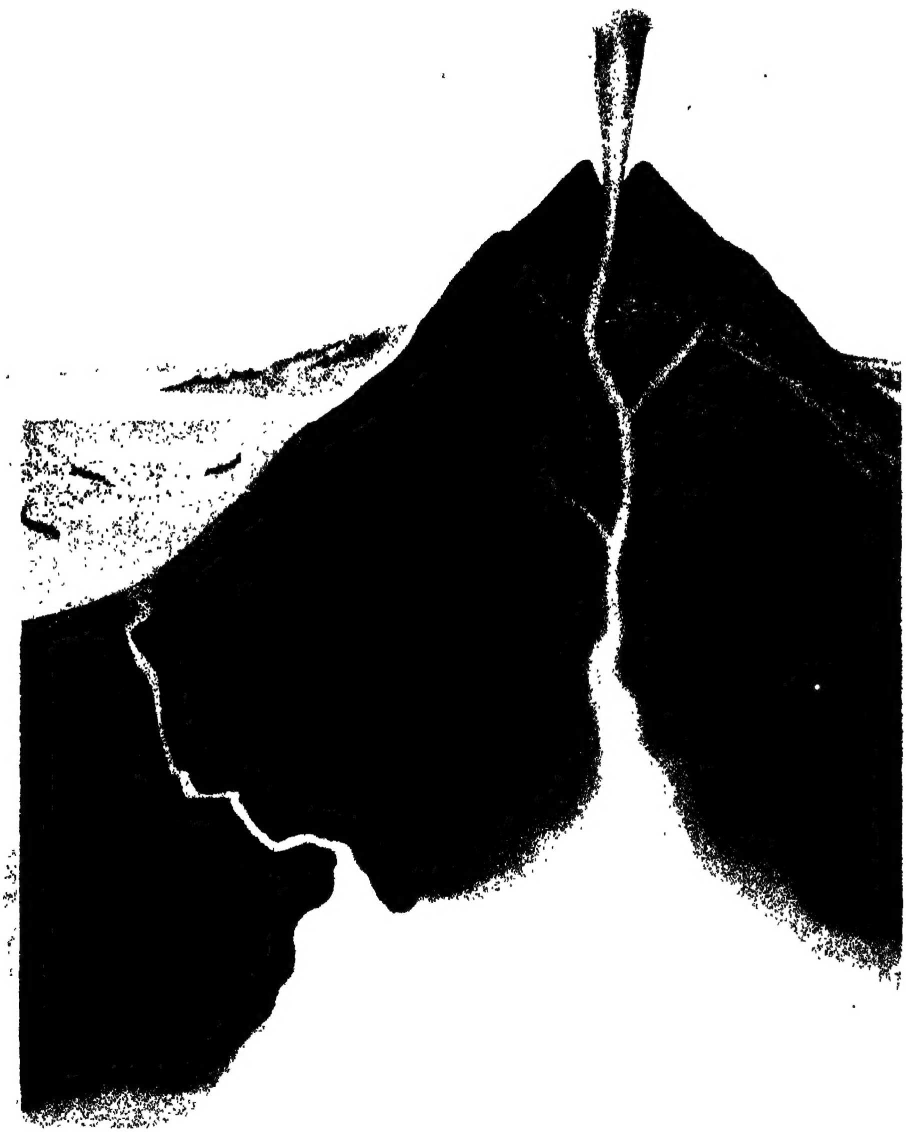
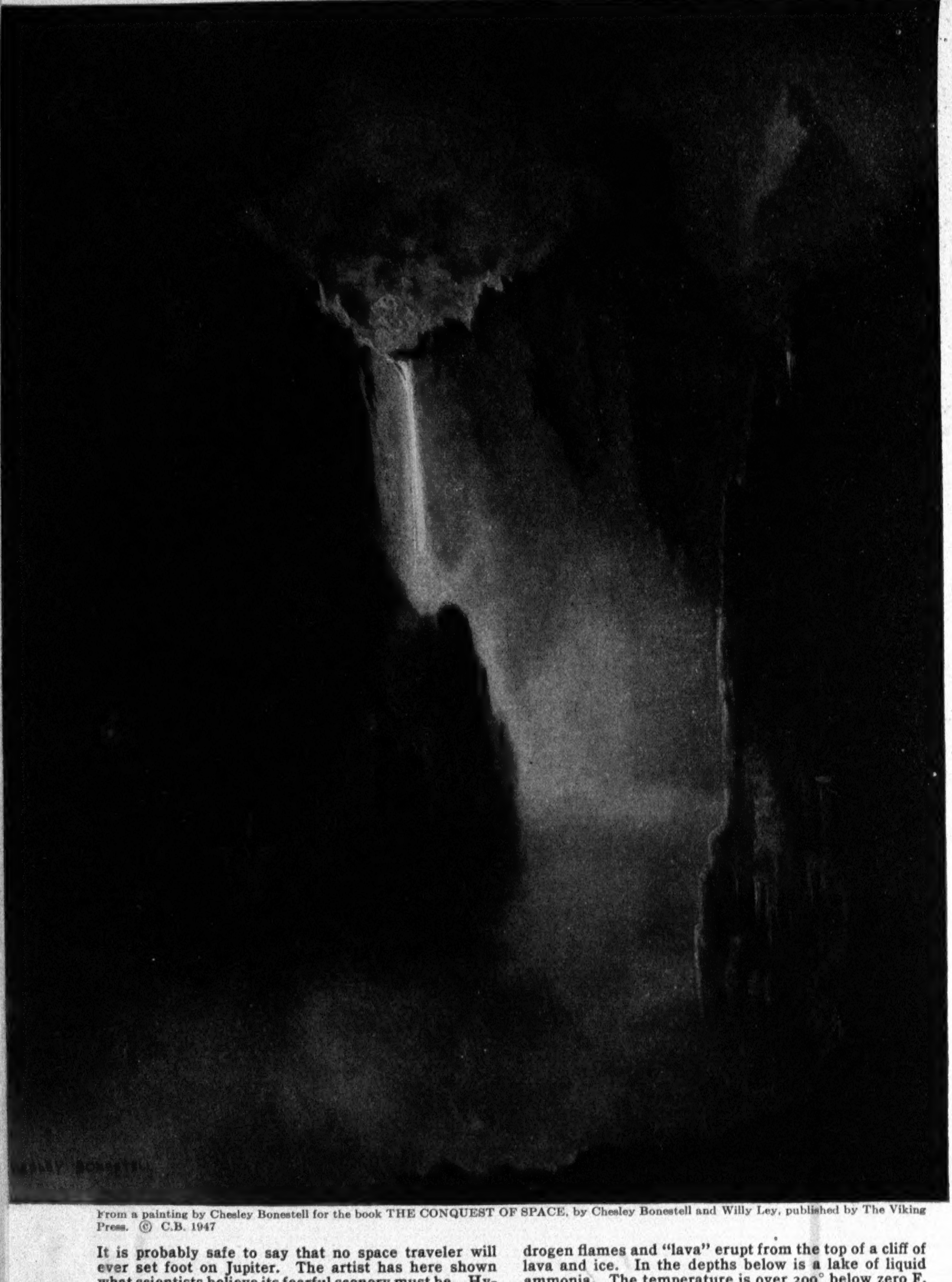




If you are blessed with a fairly good imagination you will not need to take a trip in this rocket in order to form a notion of how our solar system looks. You will only need to study the diagram above, and to remember that all its distances are to be multiplied many, many billions of times. Then you will be able to see how all these gigantic sky marbles whirl in their endless journey round the sun, which is at the center of the picture. The little planet nearest the sun of course is Mercury; it makes its trip around the sun in only eighty-eight days. Just outside the path of Mercury lies the path of Venus, whose year is a little over seven months long. Since this planet never spins on its axis, half of it is very hot and the other half very cold. Then comes our own old earth, whose orbit lies outside that of Venus: you will have no trouble recognizing its face. And you can easily guess what the little crescent is that nestles beside it. Along the path just outside the earth's, the planet Mars travels. You may recognize it by the canals that some astronomers say they see upon its surface, and by the pair of moons that circle round it. Along the orbit just outside that of Mars there marches a bevy of little worldlets that we call the planetoids; probably they are the remains of a planet that in some way was shattered into bits. And then comes Jupiter, largest of all the planets. It is rich in the possession of nine moons all its own. Next beyond Jupiter is Saturn, the beautiful ringed planet that also has nine moons. Unluckily for us, the spectacle of all those moons and rings can be seen only through a telescope. Next beyond Saturn is Uranus with its four moons. Then comes Neptune, with one moon—and now we are getting very far away, indeed, into a murky realm where the light of the sun can reach only dimly, though the power by which the sun holds all these whirling bodies in place acts even here, through many millions of miles of space. It even reaches beyond, and holds Pluto, farthest planet of all, to its dim path.



Because so many of the active volcanoes of to-day lie on the borders of the continents and within the great oceans, people once thought that sea water, turning to steam in the earth's hot depths, was what started volcanic action. But while there are many volcanoes on the coasts and islands of the Pacific, there are not so many about the Atlantic. What is more, some volcanoes are found well inland in America, Asia, and Africa—far from the sea. They must have started when the molten rock inside the earth was pushed upward through some weak spot in the earth's crust until it forced a way to the surface and shot its steam and ashes into the air. It would build up a cone, shown, in the picture above, by the blue deposit. The opening through which the lava rose is called the chimney—but the red-hot mass worked into every crack.



From a painting by Chesley Bonestell for the book THE CONQUEST OF SPACE, by Chesley Bonestell and Willy Ley, published by The Viking Press. © C.B. 1947

It is probably safe to say that no space traveler will ever set foot on Jupiter. The artist has here shown what scientists believe its fearful scenery must be. Hydrogen flames and "lava" erupt from the top of a cliff of lava and ice. In the depths below is a lake of liquid ammonia. The temperature is over 200° below zero F.

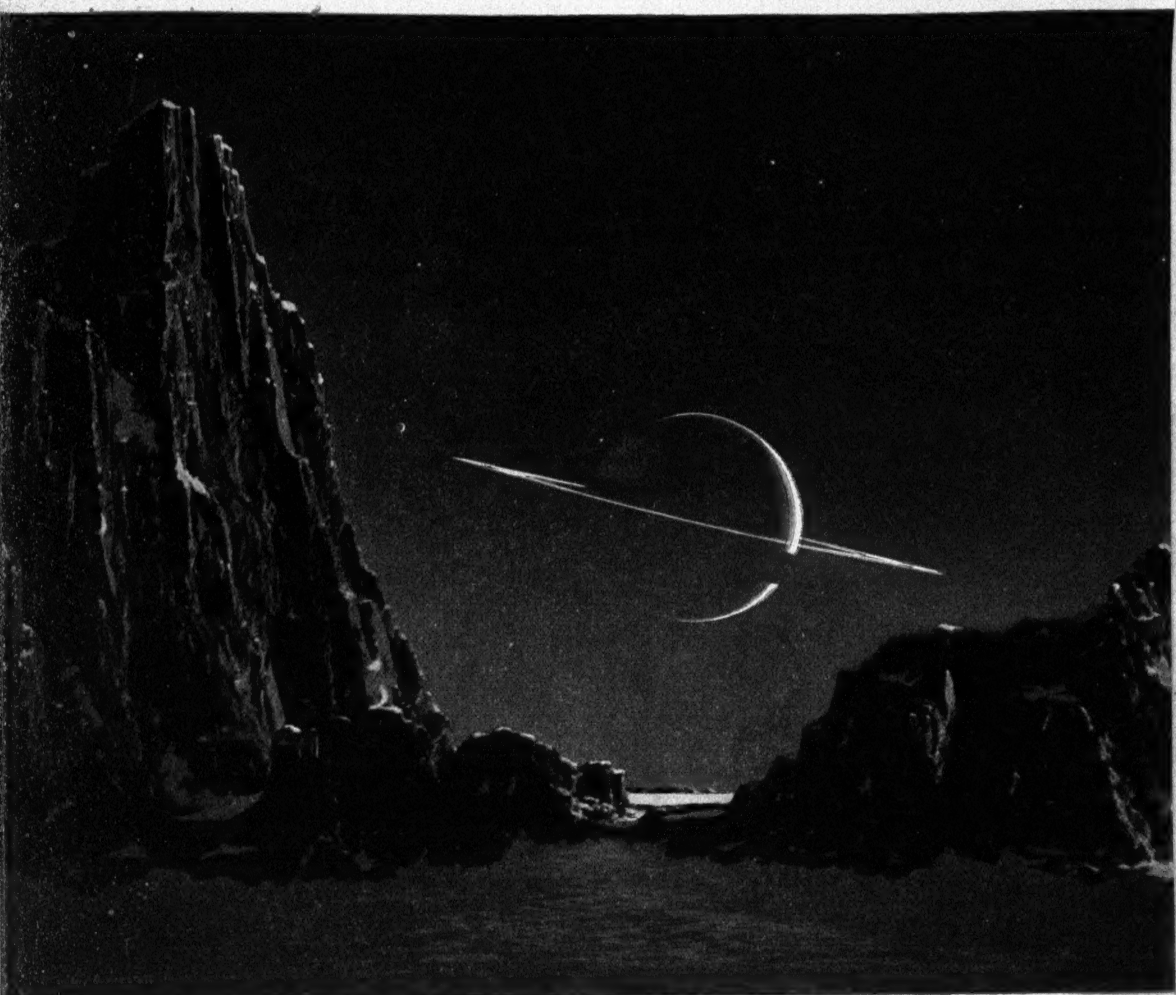
Richards Topical Encyclopedia

Edited by
ERNEST HUNTER WRIGHT
and
MARY HERITAGE WRIGHT

Editor for Canada
ALBERT WILLIAM TRUEMAN

VOLUME ONE

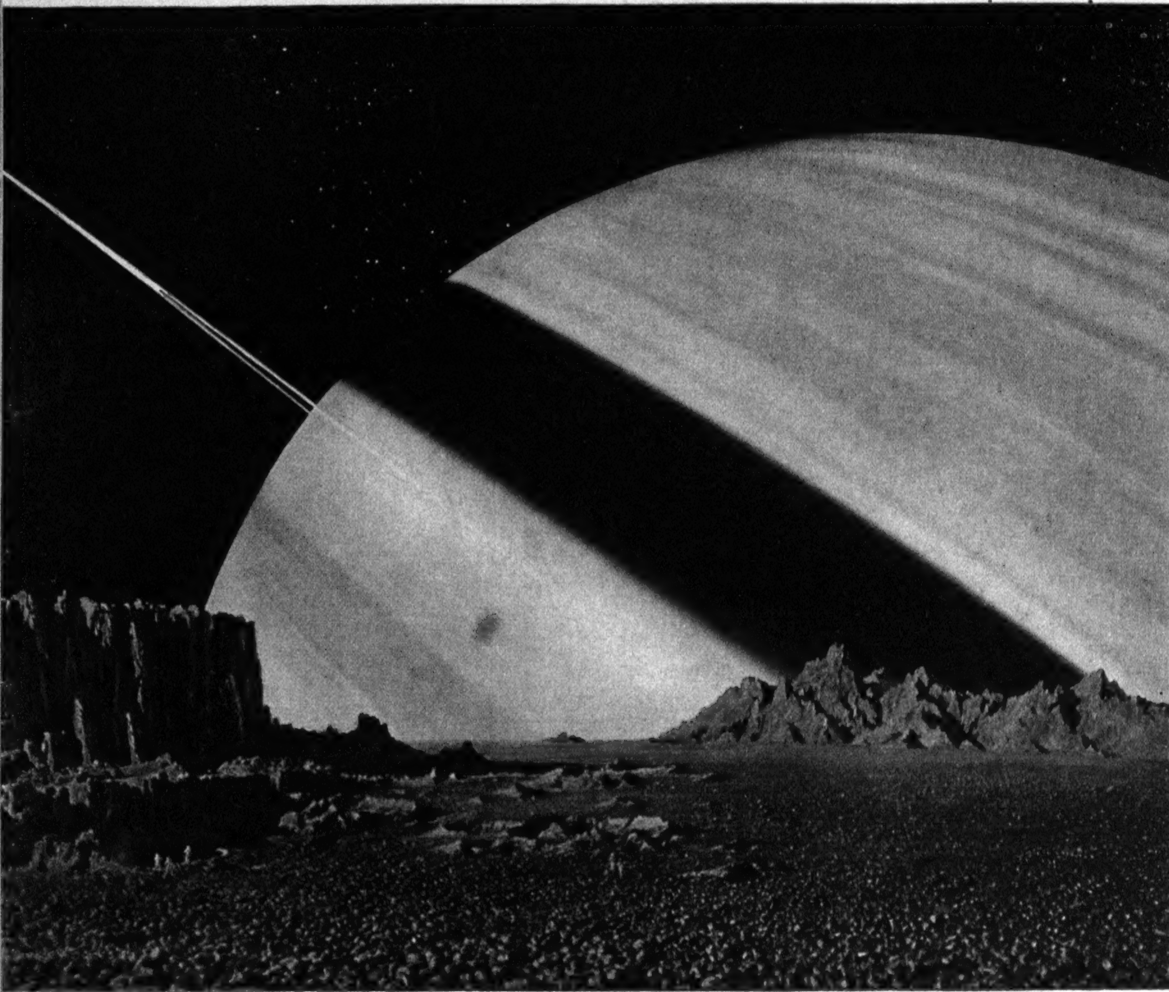
NEW YORK
THE RICHARDS COMPANY, INC.



From a painting by Chesley Bonestell for the book THE CONQUEST OF SPACE, by Chesley Bonestell and Willy Ley, published by The Viking Press.

If we could stand some evening on Titan, a giant moon of Saturn, the beautiful ringed planet would doubtless look much as it does above. Since Titan has an atmosphere the sky would be blue, not black, and we should see snow and ice. The rings of Saturn, which we see here from their edge, are very thin through, but since they are wide they cast a broad shadow on the side of the planet that is toward the sun.

PRINTED AND BOUND IN THE U. S. A. BY
KINGSPORT PRESS, INC., KINGSPORT, TENN.



From a painting by Chesley Bonestell for the book THE CONQUEST OF SPACE, by Chesley Bonestell and Willy Ley, published by The Viking Press. © C.B. 1944

Saturn is rich in moons. If we could stand on a little one named Mimas, which is only 115,000 miles from the great planet, Saturn would doubtless look much as it is shown above. We are seeing the rings from their edge, but though they are thin through and are made of nothing but cosmic dust and somewhat larger particles, they are broad enough and dense enough to cast the wide shadow you see around the center of the planet. The little dark spot below that broad belt is a shadow cast by one of Saturn's little moons. It happens to have swung between the planet and the sun. Since Mimas has no atmosphere the sky is inky black.

PREFACE

IN OFFERING to the public a topical encyclopedia the editors of the present volumes have tried to meet the needs of the library, the home, and the school. Of course we want the books to be good reading. We have done our best to make them such that anyone who opens them may find them hard to close again. Our highest hope is that they may be read just for the sake of reading—just for the voyage of discovery through which they will carry any reader around the world.

But we have a second aim, also important. We want to present our material in such a way as to make it of the highest educational value. We want the reader, at a moment's notice, to be able to put his finger upon any fact or set of facts for which he may be searching in our volumes, but more important still, we want him to find those facts so deftly correlated that he may build them into a spacious edifice rather than leave them like scattered building blocks upon the ground.

Now we could have made our articles all alphabetical, and thus have left the reader, in Dr. Johnson's words, to "beat the track of the alphabet with sluggish resolution." But following the alphabet would have forced us to split up every one of our long stories into a great many short ones, which would then have been scattered hither and yon through our volumes. Instead of one continuous story of Astronomy, for example, we should have had thirty or forty stories, in various parts of our work, on Asteroids, Comets, Constellations, Nebulae, Planets, Satellites, Telescopes, and so on through a long list. That is not the way of modern education. If knowledge is to grow into understanding, one fact must illuminate another, and the place of each be clear in relation to the whole. To that end we have forsaken custom and have presented our material by topics, that it might be of greater interest to the average reader and of wider service in the modern school.

For purposes of ready reference we have an ample and explicit index to the work as a whole, at the opening of each volume a table of contents listing the articles the volume contains, and in the "unit page" before each article a short index to the material in the unit. A list of the subjects treated in each volume is plainly stamped on the backbone. Moreover, we have tried to arrange our material in such a way as to make it handy for the reference worker. For instance, we have included, at the close of each article on a country or group of countries, a complete geographic description of the subject of the article. This device makes it easy for a reader consulting an article on a country to find out the main facts concerning the country's size, location, climate, physical features, racial elements, political divisions, and government. For the various states in the United States the material is even more detailed.

Because experience has proved that the conventional study outlines for works of this kind are too rigid to be of much use, we have replaced them with outlines, each elastic enough to be useful for readers of widely differing capacities. And because we feel that such outlines lose much of their usefulness when gathered into inconvenient seclusion at the end of the set, we have organized our outlines in the form of "unit pages" inserted through the body of the text. The reader will find that each article, or group of related articles, is preceded by a unit page, which will serve as a comprehensive plan of study for the article that follows it. This page lists all cross reference material.

It is the misfortune of most works of this sort that they grow quickly out of date. To meet this difficulty we are issuing *The Story of Our Time*, an annual publication that will include not only those statistics which are subject to change, but also a digest of world events and of the latest developments in every field of human activity—in literature, art, archaeology, science, invention, exploration, sport, finance, and all the other forms of endeavor that man's tireless energies devise. This report upon the year will be readable and authoritative, and will make a convenient reference book for any school or home. But more than that, the year book has made it possible to put into the encyclopedia only basic material which does not change. Our articles are not planned so that a paragraph may be lifted out and a new one inserted from time to time. They are a thorough and well-rounded presentation of material of permanent value. They will not soon be out of date.

BOARD OF EDITORS

BOARD OF EDITORS

FOREWORD TO THE UNIT PAGES

BEFORE each article, or group of related articles, in these volumes the reader will find a "unit page," an outline of study for the article, or "unit," which follows. It has been put there in order that what we have to say in the unit may be of the highest usefulness both to the casual reader and to the student. Because modern educational methods demand a more complete integration of the student's knowledge than did the methods formerly in use, we have adopted a new plan for presenting the matter in our books. We have avoided an alphabetical arrangement, which takes no account of logical relationships, and instead have organized our material by topics, taking pains to correlate the various parts of a subject and to build them up into a coherent whole. To do this we have divided the larger topics into a series of units of study, each unit, or chapter, complete in itself but also looking forward to the article which follows on the next page. The units bear a logical relationship to one another and build up a structure which is too impressive to be easily forgotten.

It is those logical relationships which our unit pages help to reveal. Each unit page opens with a list of references to the more important points covered in the unit. This list—headed "Interesting Facts Explained"—is in the nature of an index to the material the unit contains, and should be of use both in underlining important ideas and in furnishing the reference worker with a handy index to which he may turn as he scans the unit for material. This will often make a return to the general index unnecessary. In other words, besides the index to the set as a whole and the table of contents in the front of each volume, we have furnished still a third avenue of quick access to our material. It should be of assistance to readers of all types.

Under "Things to Think About" is a list of questions intended to start a train of reflection in the reader's mind. Certain of the questions deal with important points in the unit, and are intended to lead the reader to examine those points carefully and to hunt out the reasons for their significance. Other questions carry him beyond the confines of the material before him and lead him to speculate upon its relationship to wider matters. Such questions furnish fruitful subjects for class discussion and for good talk around the dinner table at home. While few of them are so hard as to discourage the average student, all are puzzling enough to challenge the gifted mind and to give the superior student an interesting tussle. They should be unfailingly useful and stimulating to the teacher.

Under the caption "Related Material" are gathered references to other pertinent topics in the set. Not only does this list save the teacher and student a good deal of time thumbing the index in search of correlated readings; it also opens unforeseen and interesting vistas which no index would reveal. If our volumes are to be used for supplementary reading in the classroom, this section of the unit page should save the teacher and student a good many hours of time. If the books are to be used to enrich the background in a cultivated home, it should help the reader to feel at ease in all the various fields of knowledge.

Other sections of the unit page especially adapt our books for use in progressive schools. The "Picture Hunt" is useful in visual education. "Practical Applications" relates the information in the unit to the world in which the reader lives. The ethical implications

suggested in "Habits and Attitudes" fit the unit into our scheme for character building. "Leisure-time Activities" suggests interesting projects to be carried out by a group in the classroom or by the individual reader at home. The "Summary Statement" gathers the ideas in the unit into a nutshell.

In the preparation of the unit pages the editors have had the help of Morris Meister, B.S., A.M., Ph.D.; Barbara McConnell, A.B.; Alexander Joseph, B.S.S., M.S.; Louis Eisman, B.S.; Leonard S. Bennett, A.B., LL.B., M.S.; Anastasia Hayes, graduate of the New York School of Fine and Applied Arts; Florence Meister, B.S., M.S.; Sidney Thomas, A.B., A.M., Ph.D.; Marion Osborn, A.B., A.M., Ph.D., and Margaret Pickel, A.B., A.M., Ph.D.

It is our belief that a consistent use of the unit pages will lighten the work of the teacher and enrich the background of the classroom and the home. But more than that, we believe that it will train the student in habits of study that may be useful to him through life. At least it should give him a clear appreciation of the fact that the gaining of knowledge is an intellectual adventure, never to be confused with the mere memorizing of facts.

CONTENTS

VOLUME I

THE STORY OF THE EARTH

(Geology)

(For specific facts relating to this subject consult the Index)

The story of the earth has been presented in such a way that the reader who follows the units in the order of their presentation may learn of the earth's development from a gaseous cloud into the sphere we live on to-day.

PAGE

WHERE THE WORLD CAME FROM . . . . . *Unit No. 1* xvi
(Theories regarding the earth's origin)

HOW THE EARTH RACES THROUGH SPACE . . . . . *Unit No. 2* 12
(The movements of the earth in space)

WHAT A NEW MOUNTAIN IS LIKE . . . . . *Unit No. 3* 17
(How the mountains are formed)

THE EVERLASTING HILLS . . . . . *Unit No. 4* 23

THE FIERY FURNACE UNDER OUR FEET . . . . . *Unit No. 5* 30
(The earth's hot core, geysers, hot springs, etc.)

HOW THE EARTH GOT ITS CRUST . . . . . *Unit No. 6* 37
(How the outer crust of the earth was formed)

THE GREAT AGE OF MOTHER EARTH . . . . . *Unit No. 7* 42
(How we determine the earth's age)

A LITTLE STREAM TELLS A STORY . . . . . *Unit No. 8* 45
(The work done by streams and rivers)

HOW PLANTS AND ANIMALS MAKE ROCK . . . . . *Unit No. 9* 50
(How rock is formed from the shells of plants and animals)

THE WORK OF THE BUSY CORAL . . . . . *Unit No. 10* 55
(How coral can build up islands)

WINTER FOR THOUSANDS OF YEARS . . . . . *Unit No. 11* 58
(The story of the Ice Age)

WHAT THE OCEAN HIDES . . . . . *Unit No. 12* 65
(A description of the bed of the ocean)

HOW THE SEA CARVES UP THE CONTINENTS . . . . . *Unit No. 13* 68
(The destructive work of the waves)

THE FLUES OF THE FURNACE UNDERGROUND . . . . . *Unit No. 14* 73
(The story of volcanoes)

WHEN THE EARTH SHUDDERS . . . . . *Unit No. 15* 77
(The story of earthquakes)

THE BIG HOLES IN THE EARTH . . . . . *Unit No. 16* 83
(The story of caves and their formation)

RIVERS BENEATH THE EARTH . . . . . *Unit No. 17* 88
(The story of underground water)

THE SOIL THAT FEEDS US . . . . . *Unit No. 18* 93
(How the soil was formed)

THE STORY OF THE HEAVENS

(Astronomy)

(For specific facts relating to this subject consult the Index)

For a clear understanding of astronomy the various units in the story should be read in the order in which they are presented.

PAGE

THE RIDDLE OF THE SKIES .... *Unit No. 1* 98
(The history of astronomy)

THE WHIRLING FAMILY OF THE SUN .... *Unit No. 2* 104
(The sun and the planets)

HEAT AND LIGHT FOR NINE WORLDS .... *Unit No. 3* 107
(The story of the sun)

THE ONLY CHILD OF MOTHER EARTH .... *Unit No. 4* 119
(The origin of the moon and a description of its movements in space)

THE SILVERY REALM OF MOONLAND .... *Unit No. 5* 130
(The nature of the moon's surface and an explanation of the tides)

TRAVELS IN OTHER WORLDS .... *Unit No. 6* 144
(The story of the inner planets)

A TRIP TO THE GIANT WORLDS .... *Unit No. 7* 153
(The story of the outer planets)

VAGABONDS OF THE SKY .... *Unit No. 8* 160
(The story of meteors and comets)

THE SUNS OF THE NIGHT .... *Unit No. 9* 168
(The story of the stars)

THE "CLOUDS" IN STARRY SPACE .... *Unit No. 10* 181
(The story of nebulae)

EYES THAT SWEEP THROUGH SPACE .... *Unit No. 11* 182
(The instruments used by an astronomer)

THE STORY OF THE WEATHER

(Meteorology)

(For specific facts relating to this subject consult the Index)

The Editors have developed this subject in such a way that each unit paves the way for the succeeding one. Read the units in the order in which they are presented.

HOW THE WEATHER MAKES HISTORY .... *Unit No. 1* 192
(The effect of weather on civilization and the distribution of races)

HOW THE SUN MAKES OUR CLIMATES .... *Unit No. 2* 198
(The distribution of sunlight on the earth's surface and the climatic zones resulting from it)

SUMMER HEAT AND WINTER COLD .... *Unit No. 3* 205
(The causes of the changes in temperature)

A YARDSTICK FOR THE WEATHER .... *Unit No. 4* 212
(The story of the thermometer)

AN OCEAN OF AIR .... *Unit No. 5* 215
(Things we have learned about the air)

WHAT MAKES THE WIND BLOW? .... *Unit No. 6* 221
(The cause of the air currents which we call wind)

BLOW, WINDS, BLOW! .... *Unit No. 7* 226
(Cyclones, typhoons, hurricanes, etc.)

TRAVELING MOUNTAINS OF THE SKY .... *Unit No. 8* 233
(The story of the clouds)

WHERE THE RAIN COMES FROM .... *Unit No. 9* 238
(How moisture condenses into raindrops)

UP IN A RAIN CLOUD .... *Unit No. 10* 243
(Lightning, thunder, hail, and sleet)

		PAGE
HOW A SNOWFLAKE IS MADE	*Unit No. 11*	250
(Snow, and the importance of moisture on the earth's surface)		
HOW WE WEIGH THE AIR	*Unit No. 12*	257
(Ways of measuring air pressure)		
WEATHER PROVERBS OF LONG AGO	*Unit No. 13*	262
(How our forefathers forecast the weather)		
WHY THE SKY IS BLUE	*Unit No. 14*	269
(The strange effects produced by moisture and tiny particles in the air)		
WHAT THE WEATHER MAN DOES	*Unit No. 15*	273
(The fascinating work of the weather man)		

THE LAWS OF THE UNIVERSE

(Physics)

(For specific facts relating to this subject consult the Index)

Our story of physics begins with the formation of matter and continues with a series of units so arranged as to help the reader understand each step in the subject if the units are read in the order in which they are presented.

THE CEASELESS ROUND OF MATTER	*Unit No. 1*	279
(Old and new theories regarding the nature of matter)		
HOW MATTER BEHAVES IN MOTION	*Unit No. 2*	285
(A study of various kinds of motion)		
WHAT MAKES MATTER MOVE?	*Unit No. 3*	293
(Galileo's experiments with falling bodies, and an explanation of what a "force" is)		
THE FORCE THAT HOLDS THE UNIVERSE	*Unit No. 4*	298
(The mysteries of gravitation)		
WHAT ARE THE LAWS OF MOTION?	*Unit No. 5*	305
(The interesting laws that control motion)		
WHAT MAKES A MOVING THING STOP?	*Unit No. 6*	314
(How friction can affect a moving object)		
THE REAL SECRETS IN MACHINERY	*Unit No. 7*	322
(The fundamental principles in the world's simplest machines)		
WHAT IS WORK? WHAT IS ENERGY?	*Unit No. 8*	332
(An explanation of these important scientific terms)		
HOW ENERGY GOES ON FOR EVER	*Unit No. 9*	342
(We cannot create or destroy energy)		
ARE ATOMS AND MOLECULES REAL?	*Unit No. 10*	353
(How we prove that matter is made up of atoms and molecules)		
HOW WE PUT LIQUIDS TO WORK	*Unit No. 11*	362
(The interesting story of water and how we harness it)		
THE WONDERFUL GAS IN WHICH WE LIVE	*Unit No. 12*	371
(What the air is made of)		
THE DANCE OF THE MOLECULES	*Unit No. 13*	378
(How heat affects the molecules)		
HOW FAST DO MOLECULES MOVE?	*Unit No. 14*	387
(How we measure the temperature of things)		
HOW DOES HEAT TRAVEL?	*Unit No. 15*	394
(Good and bad conductors of heat, and the reason why hot air rises)		
BOILING, CONDENSING, MELTING, FREEZING	*Unit No. 16*	401
(How matter is changed by heat)		
WHAT A RAY OF LIGHT CAN DO	*Unit No. 17*	411
(Old and new theories of light waves)		
HOW LIGHT BEHAVES	*Unit No. 18*	421
(Interesting facts concerning the behavior of light)		

PAGE

WHEN A RAY OF LIGHT FALLS ON YOUR EYE . . . . *Unit No. 19* 435
(The eye, the camera, color, and the spectroscope)

HOW A SOUND IS MADE . . . . *Unit No. 20* 442
(What it is that produces sound and why we can hear it)

HOW CAN A FLY WALK ON THE CEILING? . . . . *Unit No. 21* 451
(The story of air pressure and the vacuum)

HOW WE PUT THE AIR TO WORK . . . . *Unit No. 22* 457
(The uses we make of compressed air)

WHAT IS THE HEAVIEST THING IN THE WORLD? . . . . *Unit No. 23* 466
(The weights of various substances)

WHY A HOT THING IS BIGGER THAN A COLD ONE . . . . . . *Unit No. 24* 475
(Expansion and contraction)

ELECTRICITY

(For specific facts relating to this subject consult the Index)

WHAT A MAGNET CAN DO . . . . *Unit No. 1* 484
(The mysteries of magnetism)

THE SECRETS OF THE ELECTRIC CELL . . . . *Unit No. 2* 492
(How scientists captured the vast forces of electricity)

HOW WE MAKE ELECTRICITY . . . . *Unit No. 3* 501
(How electricity is generated)

WHEN THE ELECTRONS START FLOWING . . . . *Unit No. 4* 512
(How we put electricity to work)

HOW THE ELECTRONS WHIRL OUR WHEELS . . . . *Unit No. 5* 521
(Light, heat, and power through the wires)

CHEMISTRY

(For specific facts relating to this subject consult the Index)

WHAT IS AN "ELEMENT"? . . . . *Unit No. 1* 529
(Old and new theories regarding the elements)

WHAT IS AN ATOM AND A MOLECULE? . . . . *Unit No. 2* 539
(How the tiniest parts of an element join to form the substances that make up the universe)

SOME STRANGE DEEDS AMONG THE ATOMS . . . . *Unit No. 3* 549
(How the elements combine and make many compounds)

THE ENERGY LOCKED UP IN THE ATOM 558A
(How man learned to change solid matter into vast amounts of energy and ushered in a new era for the human race)

ELECTRONICS

(For specific facts relating to this subject consult the Index)

ELECTRONICS: MAN'S NEW SERVANT . . . . ***Unit No. 1*** 560
(How electrons in glass houses make devices that can hear, see, feel, taste, remember, measure, count, and talk)

A WAY TO EXTEND OUR SENSE OF TOUCH . . . . ***Unit No. 2*** 565
(How radar helps the aviator to see through clouds and will warn of the approach of an enemy plane)

COLOR PLATES

FACING PAGE

VOLCANO ... *Frontispiece*

THE SOLAR SYSTEM ... 98

MERCURY ... 144

VENUS ... 145

MARS ... 152

JUPITER ... 152

SATURN ... 152

SATURN ... 153

STAR MAPS ... 178

HOW LIGHT BEHAVES ... 435

KEY TO PRONUNCIATION

ā, as in māte
ȧ, as in senȧte
â, as in hâir
ă, as in hăt
ä, as in fäther
ȧ, a sound between ä and ă, as in cȧstle
ch, as in chest
ē, as in ēve
ė, as in rėlate
ĕ, as in bĕnd
ẽ, as in readẽr
g, as in go
ī, as in bīte
ĭ, as in ĭnn
k, as in key
K, the guttural sound of ch, as in the German *ach*, or the Scotch *loch*
n, as in not
N, the French nasal sound, as in *bon*
ng, the English nasal sound, as in strong
ō, as in bōne
ȯ, as in Christȯpher
ô, as in lôrd
ŏ, as in hŏt
oi, as in toil
o͞o, as in so͞on
o͝o, as in bo͝ok
ou, as in shout
s, as in so
sh, as in ship
th, as in thumb
th, as in thus
ū, as in cūre
u̇, as in accu̇rate
û, as in fûr
ŭ, as in ŭs
ü, a sound formed by pronouncing ē with the lips in the position for o͞o, as in the German *über* and the French *une*
zh, as in azure
', an indication that a vowel sound occurs, but that it is elided and cannot be identified, as in apple (ăp''l)
A heavy accent (′) follows a syllable receiving the principal stress, and a lighter accent (') follows a syllable receiving a secondary stress.

Reading Unit
No. 1

WHERE THE WORLD CAME FROM

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What every substance on the earth contains, 1–2, 11

What makes substances on the earth stay together? 1–2

What keeps the earth revolving around the sun? 1–2, 9

What are the flames on the sun? 1–4

What do we believe to be the origin of the planets? 1–6-9

How did the earth get its crust? 1–9, 11

What causes the tides? 1–9

How did the earth's first rain occur? 1–11

Things to Think About

What would happen if gravitation ceased?

What happened to the tenth planet of our solar system?

Are metals always solids?

What was the basis for the formation of early rock?

What would the earth be like if no water had formed?

Picture Hunt

What happened to part of the sun, according to the "tidal" theory? 1–7

What is the arrangement of the planets of the solar system? 1–7

What does a nebula look like? 1–4

What does newly hardened igneous rock look like? 1–8

Related Material

What did Kepler discover about our planets? 1–288-90, 13–399

How do we know what planets and other heavenly bodies are made of? 1–187-88

Why do we not communicate with Mars? 1–152

What causes earthquakes? 1–81-82

How does water help to make rock and soil? 1–363

What is the difference between the earth and a star? 1–105-6

Why is all matter said to be electricity? 1–499, 541, 542, 13–3

What were some early beliefs about the earth? 1–100-3

Leisure-time Activities

PROJECT NO. 1: Make a chart of the solar system, 1–5, 7.

PROJECT NO. 2: Make a drawing of Saturn and its rings, 1–6.

Summary Statement

Scientists believe that the earth and the other planets were formed from the sun by an accidental collision or by gravitational pull between the sun and a nearby star.

WHERE *the* WORLD CAME FROM

Why It Started in a Vast Mist and Ended in the Stout Little Ball We Live On

WE LIVE in a world of magic. Have you ever stopped to wonder where the common things around you came from—the clothes you are wearing, the books you take to school, the dishes you eat from, and your rubber ball? All of them used to be vastly different from what they are to-day. They have undergone changes that would make a magician turn pale with envy.

Let us look at your pencil for a moment. To put it in your hand, Science waved her magic wand, got a substance called graphite out of the earth, mixed it with clay, and so made the "lead" with which you write. The wooden case around the lead was once part of a lofty tree. So was the eraser; it once flowed as juice from a rubber tree—in far-off Africa, Brazil, or India. Even these substances had already been marvelously transformed. The graphite and clay were not always graphite and clay. Once they floated around in space in the form of gas.

In this way we may ask the origin of everything around us—and the answer will always be equally amazing. A wise man is never satisfied with the first easy answer he gets. He pushes his questions farther and farther back until he comes at last to the question that we all must ask sooner or later. You have probably asked it many times yourself. Where did the earth itself come from? What was it made of?

There is an old story of a magic carpet on which people could travel swiftly through space. Perhaps you have envied the men who were lucky enough to take a ride on it. But we too have a magic carpet. We call it the Imagination. We are going to climb on it now and go back to the very beginning of the world. Because we are moderns we shall take along a guide—something the travelers in the old story lacked. Our guide is a very learned person named Science, or Knowledge; and he owns a magic telescope through which invisible things may be clearly seen.

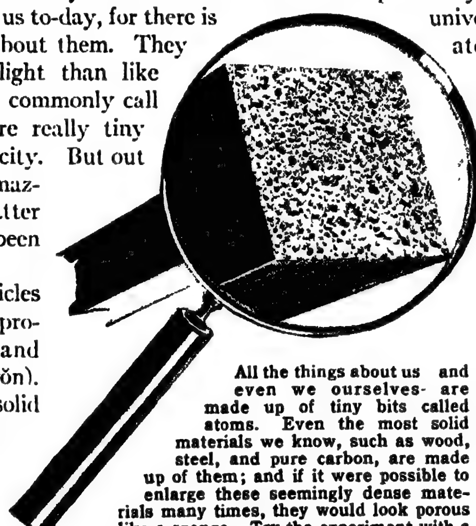
When we arrive at the beginning of time—"In the beginning," as the book of Genesis says—we find that all is darkness. But our able guide carries a magic lamp, from which he sheds a flood of light. Even so we can see nothing but empty space—"without form and void."

But our guide tells us to keep on looking, and even as we watch we see small specks or particles beginning to take shape. When we ask our guide where they come from, he can only shake his head. He says he does not know.

The Bricks of the Universe

How they ever started is the deepest of mysteries, he says, but what they now are is fairly clear. They are the tiniest known bits of matter. Not that they look at all like the matter all around us to-day, for there is nothing "solid" about them. They look more like light than like anything that we commonly call matter. They are really tiny particles of electricity. But out of them, in an amazing way, all the matter in the world has been made.

For these particles are of two kinds—protons (prō'tŏn) and electrons (ē-lĕk'trŏn). Now nothing solid can be made of protons alone or of electrons alone; but when protons join with electrons they form what is known as an atom (ăt'ŭm) of matter. Even atoms are much too small to be seen. A million of them side by side would not reach across a hair. Yet these invisible specks are the bricks that build up the world and everything upon it. Indeed, they make up the whole universe.



All the things about us and even we ourselves are made up of tiny bits called atoms. Even the most solid materials we know, such as wood, steel, and pure carbon, are made up of them; and if it were possible to enlarge these seemingly dense materials many times, they would look porous like a sponge.. Try the experiment with a piece of wood and see if the wood does not look as you see it in the picture.

"But how," we ask our guide, "could a huge world be made from such loose, invisible particles?"

It is an interesting story.

Every little atom in the universe has countless invisible "arms." With these it reaches out and takes hold of all the other atoms near it, as if trying to join with them. The arms of a single atom are not very strong, but when several atoms come together and make up what we call a "molecule" (mŏl'ē-kūl), the arms of this new body are a good deal stronger. Its greater strength of arm enables it to pull other atoms into it more easily; and also to pull at the other molecules growing up around it, and to join with them in new and larger bodies. Each new and stronger body will keep on drawing other bodies into it; and so the work will go on until our first tiny particles of electricity have been built up into all the kinds of matter that we know so well—gases and liquids and solids.

The power by which every atom in the universe pulls at every other atom is called gravitation (grăv'ĭ-tā'shŭn)—the mysterious force that holds all creation together. It is gravitation that keeps us all from falling off the earth. It is gravitation that keeps the earth from dashing away from the sun. It is gravitation that holds all the stars to their places in the sky and keeps them from dashing off forever. But in spite of all we have found out about the way in which the force of gravitation rules the universe, the force itself is still a mystery to us.

We know how it acts, but we have no notion what it is. Perhaps we shall never know. It is as mysterious as the origin of the first bit of matter. For now as we are being whisked home again on our magic carpet, our guide hastens to say that the arms by which the atoms seem to pull at one another are not really arms at all. He just called them arms because he could not think of any better word. Indeed he hardly knows what to call them. All he knows about them is the way they pull. Only with our magic telescope could we have seen them pulling atom into atom, and molecule into molecule. No mortal eye could ever have seen such a sight. For we have been watching the very act of creation. We have been looking at the birth of matter.

Suppose we should get up some morning and find that the sun had suddenly stopped

How many millions of times has the sun peeped over the Alps! Yet the Alps are very young compared with the great age of the sun, and so—for a longer time than anyone could possibly imagine—that shining disk was rising and setting before it found any Alps to peep over!

shining. What a strange and terrible place the world would seem! Our only light would be a pale, dim glow from the far off stars. The moon would have gone out, of course, for all her light is merely a reflection of the sun. The plants would die. The earth would grow terribly cold, colder than anything man has ever felt. All living creatures would perish, and in a little while the seas would turn to solid ice.

Could all this ever happen? How long will our sun keep on shining? And how did he get so hot that he can keep on warming us so long?

For an answer we had better summon our good old guide and get him to take us way back again to the beginning of things—to the birth of the sun.

When the Earth Was a Gigantic Cloud

As we draw near the great event he opens the shutter of his magic lamp and lights up the space around us. Once more we are looking at the billions of atoms that were just being born the last time we were watching. We may now notice that they are all moving about in space as they tug and strain at one another with all their might, and as they slowly draw closer and closer together, they form something that looks like a gigantic cloud.

The First Light Ever Made

At first we can see the cloud only when the shutter of our magic lamp is open, for all space is darker than the darkest night. But as the atoms swarm closer and closer together, the whole cloud must keep shrinking or getting more and more dense. Of course it is still a very misty affair, and we can see right through it as if it were the thinnest kind of haze. Still it does keep getting thicker and thicker, until—

Suddenly our guide shuts off the lamp, and lo! all space is glowing as with a fiery mist.

It is the first light ever made, and the first heat. It is the light and heat that are still burning in our sun to-day!

But what made the cloud get hot? We are none too sure about it all, but at least we know that when matter shrinks it often gets warmer, and that when it shrinks a great deal it will get terribly hot. We have no real notion why it does so, but we know

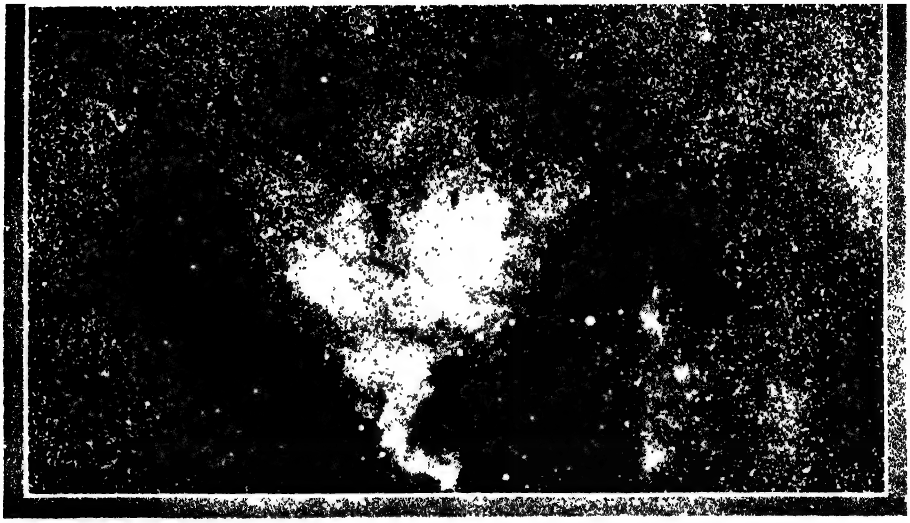


Photo by Yerkes Observatory

This is one of the vast fiery mists we call nebulae. Scientists believe that it was from some such gaseous mass as this that the sun and all the children of the sun were finally evolved.

it always does. So we believe our first great cloud kept shrinking until it turned into the fiery mist we have just seen; and we also believe it went on getting smaller and hotter till it finally became the sun above our heads.

Is There Fire on the Sun?

But we must not suppose that what we are calling the fire in the ancient cloud or in our modern sun burns like any of our fires on the earth. It takes air to make our fires burn, and without air we could not even strike a match. But there was no air in the fiery cloud, nor is there any in the sun. And any fire in the air will burn up and go out, but the fire in the cloud or in the sun can never go out in the same way as the fire in our stove. For in truth it is not really fire and it does not really burn at all. It is just heat. In a vacuum, or an airless place, a thing may be very hot without burning up; the white-hot wire in an electric bulb will last for months because the bulb is almost a perfect vacuum. Just so the sun is unimaginably hot, but it is going to last for ages upon ages because it floats in a vacuum that is really perfect. Big as it is, it would some day burn out if it were actually on fire. But it is just hot, and it goes on keeping hot. It will keep this up for millions and millions of years. In some dim future it may possibly cool off, but burn up it never can!

As our magic carpet wafts us gently home, our guide adds one more explanation. There is a very handy little word, he says, that we must often use when we are talking about things that happened millions and millions of years ago. The word is "theory" (thē'ô-rĭ). When we give the best reason we can find for anything, and yet cannot really prove that the reason is the right one, we are offering a theory. Now most of the things our guide has just been telling us are theories, for most of them have not been really proved. Sometimes we call them hypotheses (hī-pŏth'ê-sēz). They are the carefully formed beliefs of many wise men who have spent their lives in the study of the earth and the stars. Certain other wise men who have studied just as hard have offered theories that are different, and the wise men of the future may tell us something different still. Our guide says he has told us what most of the wisest men believe at present.

Where the Earth Came From

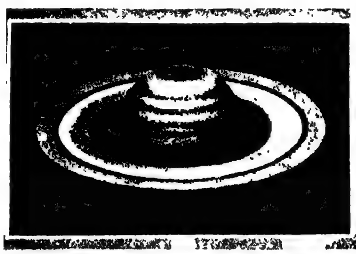
But we have many a question left to ask our guide. He has shown us the birth of

This is how the sun may once have looked, according to the Nebular Hypothesis of Laplace The sun had done a lot of spinning and shrinking before it reached the stage you see above. As it spun and shrank, it began to flatten at the poles and to bulge out all around the equator. Then, one by one, by centrifugal force, it began to throw out the ten great rings of gas which you see encircling it above.

Then, according to Laplace, the rings of gas began to condense around one or more of their larger particles. By a long, slow process each ring condensed into a round ball of gas very much like its parent sun. These new balls of gas began to throw off rings—just as they had been thrown off by the sun. These rings became moons. Above, you see the solar system. One of the planets was broken up into little "asteroids."

matter, and has given us a glimpse of the infant sun. Now we want to ask him where our own earth came from—as well as the other planets which all whirl around the sun in the way our earth does.

Our old guide will be very honest about this. He will begin by telling us that nobody really knows for certain how the earth got here. Then he will add that there are three great guesses, or theories, about the birth of the earth and the other planets, and that any man who is wise enough may take his choice of the three. Our guide will tell us what the guesses are, and will give us the main reasons for and against each one of them.



This is Saturn, the great planet which is surrounded by rings. In just the same way the sun would have been surrounded by rings, according to Laplace's theory as to how the solar system came into existence.

The first guess is the famous Nebular (nĕb'ū-lăr) Hypothesis, invented by the French astronomer Laplace (lä'pläs') more than a century ago. Millions of years ago, Laplace tells us, the sun must have been a great ball of gas far larger than it is to-day—perhaps as large as the whole orbit of Neptune is now. This vast ball of gas was spinning round, and it was also shrinking in size. The shrinking came simply from the pull of gravity, as all the particles of gas tended to fall or condense around the center.

When the Earth Began to Shrink

Now what would happen to a spinning ball of gas that was constantly getting smaller?

For one thing, the smaller it grew the faster it would spin. You know that to be true, for you have watched the water flowing out of a basin through the pipe at the bottom—the lower the water gets in the bowl, the faster it spins in its little whirlpool around the opening of the pipe. You know it, too, if you are an expert on the horizontal bar—for when you are doing a "giant swing" at arm's length you will be going fairly slowly, but if you quickly double up around the bar, and tuck in your legs, you will at once whirl a good deal faster. In the same way the sun spun around faster as it kept shrinking to a smaller size.

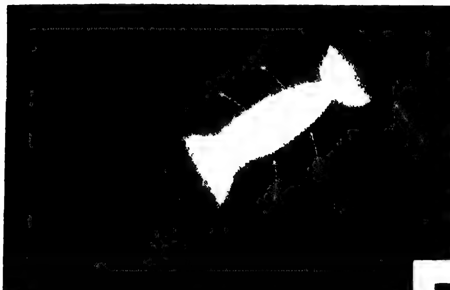
Then of course as the gas ball spun faster and faster it began to flatten at the poles and to bulge out all around the equator. Anybody knows it ought to do that. When its speed had grown rapid enough, it threw off a great ring of gas all around the equator—more or less like one of the rings around Saturn to-day. It threw off this ring into space simply through centrifugal force—the force that makes drops of water fly off from a spinning wet ball. As the sun shrank still more and went still faster, it threw off another ring; and then another and another, until there were ten in all.

Next these rings of gas began to condense around one or more of their larger particles. It was slow work, of course, but there was plenty of time. In the long run each ring condensed until it had turned into a ball of gas, very much like the parent ball of the sun, but very much smaller. Thus each ring turned into a round planet. These gaseous planets were all spinning too; and most of them threw off one or more satellites, or moons, in the same way they had themselves been thrown off from the sun.

As the ages passed, these planets cooled. From a ball of gas each turned into a ball of liquid and then into a ball of solids. Thus they came to be the earth and Mars and Jupiter, and all the other children of the solar system as we see them in the sky to-day. In the center of them all is the parent sun, still spinning and still very hot. It is so much larger than the ten planets it threw off that it has not had time to cool.

But we are saying that the sun shot off ten planets, and we have found only nine of them. And thereby hangs another tale. Long, long ago one of the planets seems to have met with some terrific accident that shattered it into thousands of pieces. We have found many of these bits in the heavens, and we call them asteroids (ăs'tĕr-oid)—"starlets"—or minor planets. They are really tiny worlds that keep to their regular paths around the sun just as their big brothers do.

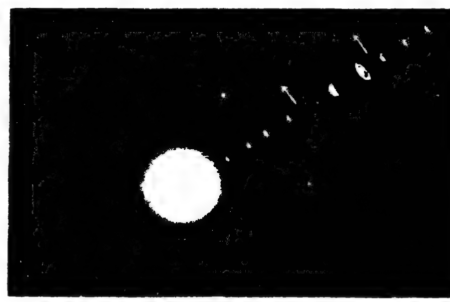
Now all that, our guide says, is the first guess as to how the world was born, or the Nebular Hypothesis. He says he used to think rather better of it than he does now. He now finds it pretty hard to believe, and for the following reasons: He does not think the sun was spinning fast enough to throw off those rings so long ago; and even so, it would have thrown off hosts of separate particles and not any such ring as we have been describing. Nor would these rings running all the way around the sun have ever condensed into round . ..... Nine of the satellites, too, are whirling the wrong way—in a direction opposite to the one they would have to follow under this theory. For these and other reasons our guide has just about given up the theory.



If the "tidal" theory of Sir James Jeans is anywhere near the truth, it was a lucky chance that brought the giant tramp star so near our sun. Otherwise the "cigar-shaped" arm you see above would never have been pulled out from the sun, the planets would never have been formed, and you and I would never have been born!

He thinks better of the second guess, the "tidal" theory of Sir James Jeans, a great astronomer of our own day. This theory starts with a sun a good deal like the first one—a vast ball of gas, possibly as big as the orbit of Neptune, very thin on the outside but much denser near the center, and perhaps not spinning in a slow rotation. At some time ages ago, Jeans thinks, some giant tramp of a star—another sun, of course, and a bigger one than ours—came whizzing by, very close to our own sun. It must have come within a few diameters of our sun. Now what would happen when this amazing visitor came along?

The other star would pull out a great "arm" or filament of gas from our sun—Jeans calls it a "cigar-shaped" arm. At first the arm would be pulled straight out from our gaseous sun, or straight toward the other star. But since the other star is dashing onward at a dizzy speed, the arm would next be pulled after it on its path; and so the arm would get a motion not only *away* from our sun, but *around* our sun as well. Then more and more matter would be pulled out by the sublime visitor, and treated in the same general way—though it may not be drawn so hard or so far, since the visitor is passing very rapidly and now has less time left for pulling. And now the great tramp star passes on into space Most of the gas in the arm probably falls back into our sun. But not quite all of it; some of it has taken on such a speed *around* the sun that when it falls back toward that body it does not quite fall in. It misses the sun, and goes on around it. But it cannot get away from the sun, which holds it by the pull of gravitation; and so it goes on whirling around the sun, with the motion given to it by that passing star.



Here are all the children of the sun as they evolved from the "cigar-shaped" arm. The nearest to its parent sun is Mercury, the smallest of the lot. Next come Venus, the earth, Mars, the asteroids, Jupiter, Saturn, Uranus, Neptune and finally Pluto. The last, which is farthest of all from the sun, was not discovered until quite recently.

The matter that was thus separated from the sun was probably not of the same density throughout. Slowly it began to gather or condense around the various denser centers in it; and of course the denser these centers grew, the faster the work would go on. In this way the gaseous matter gathered into

Photo by Chauffourier, Rome

This strange waste land is a lava field of Mt. Vesuvius, where new masses of molten lava are constantly pouring down to cover the old layers that have hardened. If it is true that our earth was once hot and molten, then, as it hardened and cracked and new masses of molten material oozed over it—and in turn hardened and cracked—the original crust of the earth may have looked somewhat like this.

the ten centers which were later to be the planets, all revolving around the sun.

Then where did the moons come from? Most of them were torn out of the gaseous planets the first time the planets passed nearest the sun as they started around it—just as the planets themselves had been torn out of the sun by the tramp star. Two of the planets, Mercury and Venus, may have been small enough to condense and turn to liquid before the sun had a chance to pull away a chunk from them, and that may be the reason why these planets have no moon. On the other hand, the larger planets, Jupiter and Saturn, must have remained gaseous much longer, and may have been made of thinner gas in the beginning; and that may be why nine moons were pulled out of each of them.

The Birth of the Planets

All of the planets then had about the same history as we gave them under the other theory. They turned slowly from gas to liquid and then to solid balls, whirling around the sun and taking various periods to make the circuit according to their size.

Is Our World a Lucky Accident?

That, in brief, is the "tidal" theory. We do not quite know whether it is true or not, but the greater number of the scientists today believe it. Our notion of the heavens is a very different one according as we believe the nebular hypothesis or the tidal theory. Under the nebular hypothesis most or all of the suns in the universe ought to behave in about the same way in throwing off planets, and each of them ought to be the center of a solar system more or less like ours. In other words, there ought to be millions of worlds in the sky. But with the tidal theory there would never be any worlds except after the very rare accident of one star passing very close to another, and tearing away a chunk of it. Exceedingly few suns would ever have

any planets, and the few worlds in our own solar system would be about the loneliest things in space. Even among these few worlds the earth may be the only one that can support life, and so life as we know it here would be the grandest of accidents in the universe.

The Third Guess

There is still a third guess, called the Planetesimal (plăn'ĕt-ĕs'ĭ-măl) Hypothesis. This also argues that the earth and other planets were pulled out of the sun by a passing star, but that the gas thus detached cooled down into little solid bodies, perhaps about the average size of nuts, and that these gradually gathered together in solid masses to form the planets. The heat caused by their collision would be enough, it is argued, to make them melt and fuse together. This theory is held by some of the American scientists, but by few others, and by geologists rather than astronomers.

We ought to say again that nobody really knows which of these three theories is true, or whether any one of them is true. Some day, perhaps, we may have a theory that will eclipse them all.

Why Planets Keep on Spinning

All of the planets were drawn out of the sun whirling in the same direction as the sun itself, and for millions upon millions of years they have most of them kept on whirling, or rotating (rō'tāt-ĭng), and so turning all their sides to the sun in turn. This causes day and night on them. If you are surprised to know that they keep right on spinning, you must remember that there is practically nothing to stop them. A thing that is moving will keep right on if there is nothing to stop it, just as a thing that is at rest will never move unless there is something to start it.

If we have a hard time believing this, it is only for the reason that all the things we ever see moving on our earth will soon come to rest because there is so much to stop them. We throw a ball and at once the air begins to slow it up; gravity soon pulls it down to earth, and rubbing along the earth, or friction, brings it to a pause. The same thing happens to a bullet. But nothing of the kind will happen to a planet. The planet is not moving in air but in empty space; its own air, if any, is all moving with it. There is nothing in empty space to rub against it and slow it up. So it will go on for a very, very long time.

But not forever. For little by little the old earth, like all the other planets, is slowing down. The tides of the sea, caused by the pull of the moon and the sun, help to make it go a little bit slower all the time. The tides cause a certain amount of friction, and part of the earth's energy of rotation is given off in the form of heat. Of course the tides are the lightest of brakes on the big ball—lighter than a single strand of spider's web in the path of a cannon ball. Yet if there were enough strands they would finally stop the ball. One of these days our earth will also stop—but not for countless millions of years.

Was the Earth Once a Ball of Gas?

Have you ever looked inside the blast furnace of a great steel mill? If so, you have seen molten iron, and have perhaps thought that nothing could be hotter than iron that was hot enough to pour. Yet iron can be made to pass through a much more amazing change than this. In a temperature a great deal higher still, it will boil and turn to gas or vapor—just as water boils and turns to steam. We can hardly think of a heat great enough to turn iron and other metals into gas.

Yet, according to the hypothesis of Sir James Jeans, our friendly earth was once so hot that it was all gas. For when it was first drawn out from the sun, the sun itself was a great mass of seething vapor, held together by the pull of every atom in it upon all the other atoms. For millions of years the earth kept a terrific heat, but slowly its surface cooled off enough to turn into liquid—just as the iron in the furnace was liquid before it grew hot enough to turn to gas. In its liquid state our earth must have looked very much like the molten iron in the furnace.

How the Earth Got Its Crust

Now whenever iron ore is melted, the bits of rock that are always in it rise to the top, for they are lighter than the metal. If this

Photo by National Park Service

The Hawaiian Islands were built by the eruptions of many volcanoes that rose from beneath the sea--and some of those volcanoes are still busy to-day! But the ones now active are mainly of the "quiet" type; their sides slope gently, their craters are wide, and the lava that rises and falls in their bubbling cauldrons, flows in a quiet stream when it rises above the crater walls. Kilauea (kē'lou-ā'ä) is one of the most famous of these stately volcanoes. Its crater is the largest active crater in the world. At the center of the great plain inside this crater is the seething pit shown in the picture above. Here at night one may see fountains of fire at play. The goddess Pele was the dread mistress of Kilauea; and to the glassy threads that the wind spins from the lava drops, the Hawaiians give the poetical name of "Pele's hair."

theory is true, the same thing happened when the earth cooled down. All the substances that were lighter than the heavy metals rose to the surface of the ball. And there, as they cooled off a little, they formed a kind of crust—very hot but not quite molten. Of course the crust was very thin at first, and so was forever cracking. Wherever it cracked the molten stuff within oozed out and ran over the hardened surface in every direction. But when it had also cooled, the crust was just that much harder and thicker. Then, too, the molten rock inside kept rising and adding its bulk to the under side of the crust. And so for a long time the process of making a skin for the earth went on. At last it was incased in a hard, thick shell of what we call igneous (ĭg′nē-ŭs) rock—for "igneous" means "made by fire."

The Earth's First Rock

If things happened as we have said, this was the first rock ever made on the earth, and from it came the soil and all the rocks we have to-day. But this first rock was made so many ages ago that we can no longer recognize it to-day. It has been buried, folded, remelted, and so transformed that even if it is present we cannot tell it from later igneous rocks which have gone through the same history. It has also been weathered and broken up into small bits which have gone into the making of the second great class of rocks—the sedimentary rocks, the first of which came from igneous rocks. About these sedimentary rocks we are going to speak in another place.

When the terrific heat of the young earth had been shut up inside a solid crust, some very wonderful changes came over our world. It was then, for instance, that rain began to fall.

Where the First Water Came From

Now one might easily suppose that water had always been water. But it must also have started its career in that first fiery cloud, and it could hardly have been much like water in so hot a place. Like all the other things there, it existed in the form of tiny particles of electricity. And we do not know for certain just how and when it first turned into water. But many of the scientists believe that various kinds of gas escaped from the earth after its crust hardened, through volcanoes or otherwise, and that some of the gases united to form water. For water is made up simply of two gases, oxygen (ŏk′sĭ-jĕn) and hydrogen (hī′drō-jĕn).

The Earth's First Rain

The crust of rock acted as a shield between the hot interior of the earth and the gases around it. When water was given out from the rocks that were turning solid, it took the form of a great cloud of steam, which hung over the earth for thousands of years. But as time went on, the crust grew thicker and held in more and more of the heat. Then the cloud of steam around the earth had a chance to cool. So of course it gathered into drops of water and came down in torrents of rain.

When Water Began Its Work

But the crust must still have been very hot, and the rain must have turned back into steam just about as soon as it touched the earth, just like drops of water falling on a hot stove. What a mighty hissing there must have been! Up rose the steam again in a cloud—but only to cool off and fall once more as rain. It must have taken many, many years for the warm showers to cool the earth's hot "skin." But in due time the work was done; and then the water began making some important changes on the crust of rock.

But now we must give a farewell glance at the huge ball that will one day be our earth, and then settle ourselves upon the magic carpet for our return home. Just before we start, our guide pauses to point out the thousands of twinkling stars that light up the sky. They are all suns, he says, like ours. They were all made from atoms—very, very tiny specks of matter—in the same way as ours.

Reading Unit No. 2

HOW THE EARTH RACES THROUGH SPACE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How big is the earth? 1–13
How did the earth get its shape? 1–13
How many miles does the earth travel in one year? 1–13
What keeps us from falling off the earth? 1–14
Who discovered the laws of gravity? 1–14
How much does the earth weigh? 1–16
What holds the earth in its path? 1–15-16
How do we weigh the earth? 1–16

Things to Think About

What would happen if the earth slowed down in its motion?
Suppose the earth's gravity ceased to act!
Why is not the earth pulled into the sun?
Why does not a man weigh exactly the same on all parts of the earth?

Picture Hunt

How do the planets compare in size? 1–16
Why does an apple hanging at the end of a string pull the string straight? 1–15

Related Material

Did people ever believe that the other heavenly bodies revolved about the earth? 1–100, 103, 13–393
How may a change in the earth's orbit have affected the coming of an Ice Age? 1–61
Who first found out about the Ice Age? 13–431-33
How does centrifugal force affect bodies other than planets? 1–310-12, 313
How does centrifugal force affect the moon? 1–122, 136
How does centrifugal force help us pump liquids? 1–465
What are the antipodes? 5–543

Leisure-time Activities

PROJECT NO. 1: Demonstrate centrifugal force, 1–15.
PROJECT NO. 2: Make a chart showing the relative sizes of the planets, 1–16.

Summary Statement

The earth takes one year to revolve around the sun along an almost circular orbit 584 million miles in length.

What has a little top in a vacuum got in common with our earth? Just this: they are both of them spinning away in an airless space.

HOW *the* EARTH RACES *through* SPACE

So Restless that She Has Spun Herself Out of Shape, She Travels Over Half a Billion Miles a Year

IF YOU had a great mass of molasses candy and wanted to make a ball of it, what would you do? The quickest way would be the one that Mother Nature took to make a ball out of the earth when the earth was still softer than molasses candy. She just spun it round and round till it looked like a big orange. For like an orange, though to a much slighter degree, it is the least bit bigger around the middle and the least bit flattened at the top and bottom.

The reason for that is very easy to find. If you spun your ball of soft molasses candy fast enough, it would start to swell around the middle and to flatten at the top and bottom. And the thing that makes it do so is the centrifugal (sĕn-trĭf'ū-găl) force of which we have already heard—the force that makes drops of water fly off a wet ball if we spin it. Just so, when the earth was soft and was spinning a great deal faster than it does now—five or six times faster—it was whirled a little out of shape; it swelled out a little at the middle, or equator, and flattened a little at the top and bottom, or poles. But the flattening and swelling are so slight that a true picture would never show them. The earth is only twenty-seven miles farther through at the Equator than at the Poles; and it is about eight thousand miles through at either place.

When we see the sun rising in the east, sailing across the sky, and setting in the west, we may have a hard time believing that it is standing still. But that is what it does. It appears to be scudding over the sky only because we are spinning around beneath it. In the same way, when we lie on our backs some summer afternoon and gaze up into the deep blue sky, we can hardly imagine that we are plunging along through it at the mad rate of more than a thousand miles a minute. Yet that is the speed our earth is making as she carries her billion and a half passengers on their annual trip around the sun. A bullet from the best gun in the world travels less than a mile a second, but the earth goes over eighteen miles in the same time.

Her path—or orbit (ôr'bĭt)—is 584,000,000 miles long; and the time she takes to cover it we call a "year." When she gets back to

her starting point—that is, when she has made one "revolution"—she has traced what is almost a perfect circle, though not quite; it is slightly flattened, and the sun is not exactly in the center of it. In January, the earth is 91,500,000 miles away from the sun and in July it is 94,500,000 miles away. The average distance is about 93,000,000 miles—the distance that we often call "the yardstick of the universe."

Some of the ancients used to picture the earth as a great flat plate floating on a gigantic ocean. Others thought it was held up by four big elephants, who in turn stood on the back of a huge tortoise. They would probably have found the truth still harder to believe. For the truth is that the earth rests on nothing at all. It is freer than a ball in the air, for it simply floats in empty space.

Simple people have imagined that the world was flat, and that if something turned it upside down, everything would fall off! Now you and I know that the world is round, and that it has no "upside down" or "right side up," so far as living on it goes. For the force we call gravity holds everything snugly to the earth. So the little sailboat you see above may travel anywhere over the waters of the globe. It may sink, but it can never "fall down" into space.

Yet it is held up as firmly as if it were chained with cables. The most gigantic forces in the universe are forever gripping it and holding it to its place in the vast void that we call space. And so it is with all the other planets. All their seeming freedom ends in the necessity of whirling evermore around their sun.

Nobody knew what held them in place until about 250 years ago, when the great Sir Isaac Newton found out the secret. There is a story that Newton saw an apple fall to the ground and began to wonder why an apple always comes down from the tree and never by any chance goes up; and that he kept on wondering about this until he found out the secret of universal gravitation.

The Truth about Newton and the Apple

Now the apple may well have started Newton thinking, and indeed the tree from which it may have fallen was still standing in the time of our grandfathers, when it was cut down and carefully preserved. Still the story is not quite true as it is commonly told. Long before Newton men knew why an apple fell down to the earth instead of flying up into the sky. They knew that the pull of the earth's gravity made the apple fall; and they knew that the same pull kept everything on earth from dropping off into space. They knew we should all be able to jump over the moon and never come back if there were no gravity to hold us down to earth. So the apple did not puzzle them.

But they did not know that every body in the universe—every sun and moon and planet—pulls at every other body in the same way as the earth pulls at the apple. That was Newton's great discovery. We call it universal gravitation, and we now know that it is what holds the earth and her moon, the planets and the sun and all the stars, in their precise paths throughout all the ages. All of these suns and worlds are pulling and straining at one another all the time as they plunge headlong through space, with the result that long ago they all settled down to certain paths where all the pulls and strains are equalized. There in those paths they remain. The huge balls will never skip the track by so much as an inch without good cause, will never move a hair's breadth except in accordance with the law of universal gravitation. The discovery of that law was one of the great triumphs of the human mind. Perhaps you would like to know the law by heart—it is one of the things you ought to remember all your life. Here it is: "Every particle of matter in the universe attracts every other particle with a force which is in direct proportion to the product of their masses and in inverse proportion to the square of the distance between them."

The apple which the boy in the picture above is whirling about him at the end of a piece of elastic, is trying to pull away; but the elastic keeps it from flying off. It is this "pulling away" that we call centrifugal force, and it is that force which keeps the earth from falling into the sun.

That fact is what saves us from falling off the earth, and keeps everything in its place from a pebble to a planet. The law was not easy to discover. The great Newton was twenty-two years old when he began to search for it, perhaps with a hint from the apple. At the time he was dissatisfied with the way scientists explained the motion of the moon and the planets. He had been reading the explanation of a famous Frenchman named Descartes (dā'kärt'), who thought that the moon and the planets were floating in a liquid that filled all space and were hurled around in their orbits by whirlpools in the liquid. Newton doubted this, and began to wonder whether the same thing that explained the apple would not explain the moon and the planets.

How the Sun Holds the Earth in Place

But his first calculations seemed to show that his guess was all wrong. So he dropped the matter. Then seventeen years later he heard of a new measurement of the earth, which would make a difference in his figures. And when he tried the new figures, he had the joy of finding that his guess was perfect. The secret of all the whirling in the skies was out at last.

But if the sun is always pulling at the earth as the earth pulls at the apple, why doesn't the earth fall right into the sun?

Well, take your ball and tie it to a strong piece of elastic. Then whirl it around your head and see what happens. As it swings round you it is always pulling away, and only the elastic keeps it from flying off. The faster it whirls the farther out it will pull, but the slower it whirls, the nearer it will come to you. If you stop whirling it entirely, it will be drawn into your hand.

Why the Earth Isn't Drawn into the Sun

The same thing is always happening with the earth and the sun. In place of the elastic band, the force of gravity is always trying to pull the earth into the sun. But the earth is whirling round the sun so fast—twenty times faster than a bullet from the best gun—that it is pulling very, very hard to get away. The result is that the two great pulls just equalize each other and keep the earth where it is. As long as you swing your ball around your head at the same speed, it keeps in the same circle. And that is exactly what the earth does.

As long as it keeps up its present speed, it will stay at a safe distance from the sun. If, for any reason, it should ever get up enough more speed it would fly off from the sun—just as your ball would break its elastic—and dash out on a straight line into frigid space, where it would at once be frozen. If, on the other hand, it ever slowed up enough,

it would fall right into the sun and burn up. But we need have no fear of either disaster. For a longer time than we can ever imagine, we are going to keep right on pulling away from the sun by our centrifugal force, and being pulled toward the sun by its gravitational force; and the result of the two forces will keep us right where we are, always doing our eighteen miles a second round our hot captor.

You will remember that the earth is just a little flatter at the Poles, which means that it is not quite so thick through at those points as it is on the Equator. So at the Poles a man would be a little nearer to the center of the earth. The man therefore weighs just a tiny bit more at either Pole than on the Equator. The pendulum of a clock also moves a little bit faster in the region of the Poles, for it is the pull of gravity that governs the pendulum and makes it swing back and forth at a regular speed. This would not affect your watch at the Pole, of course, for that is governed by a spring.

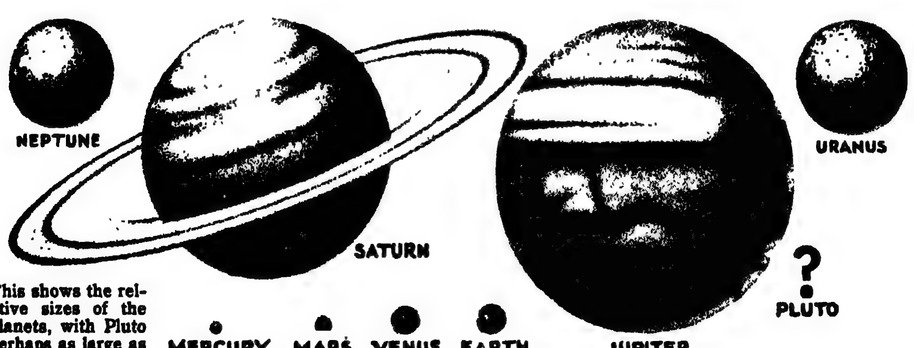
To weigh the earth! What an enormous pair of scales we should need! But maybe we can find a way to do it without scales. We usually weigh an object by putting it on a balance and seeing how much the earth pulls at it. The greater its "mass"—or the more stuff it contains—the heavier it is; that is, the harder the tug of the earth on it. It is true that every object attracts every other object, but the attraction of the big earth is so great that the attraction between other objects on its surface is not noticeable. Still we can show that the attraction does exist. For we can suspend a very light object and see it attracted by a large mass of metal, and we can even measure the force with which the larger mass pulls at the smaller one. Of course the pull is extremely slight, and we need special apparatus to detect it at all.

But if we have found out how hard a large mass—say two hundred pounds of steel—will pull at a small mass—say two ounces of gold—we can find out how much harder still the earth will pull at the two ounces of gold. And that will tell us exactly how many times heavier the earth is than the two hundred pounds of steel. You see it is a roundabout way of finding out, but just as certain as if we could put the earth on a gigantic pair of scales.

Perhaps you wonder why we cannot simply take a sample of the stuff of which the earth is made, measure it and weigh it, and then calculate the weight of a ball of it as big as the earth. The trouble is that we cannot reach far down into the earth to see what it is made of. All our samples come only from the surface; we cannot reach the core. We can tell the density of the earth only by measuring its pull on other objects. What we find is that our old earth has an enormous weight—far greater than we can imagine. Most of us cannot even give a name to so vast a sum. We will help you all we can with it; we will put it in round numbers:

6,000,000,000,000,000,000,000 TONS!

The number is six sextillion. And yet, as a matter of fact, the earth is rather a small planet, as planets go.



This shows the relative sizes of the planets, with Pluto perhaps as large as Mercury.

Reading Unit No. 3

WHAT A NEW MOUNTAIN IS LIKE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How are mountains arranged on the surface of the earth? 1–20
Which are the important mountain chains? 1–20
What are geosynclines? 1–20
How does hard rock form? 1–20
What causes mountains to rise? 1–20
What evidence is there that mountain tops were once under the sea? 1–20, 21
How old is the Appalachian chain? 1–21
How does water help to form mountains? 1–21, 22

Things to Think About

What happens to mountains when internal volcanic heat cannot escape?
What would the earth's surface be like if water did not change it?
How did sea shells get into certain rocks found on high mountain tops?
Why do we believe that new mountains will be formed in the future?

Picture Hunt

What kind of rock is shown in this picture? 1–19
How were these amazing steeples and pinnacles made? 1–18

Related Material

How are mountains sometimes used by sculptors? 11–361, 364
How may mountains be tunneled through? 10–203-6, 207
Which are the highest mountains in the world? 5–432, 441, 493
What mountains were formed during the Silurian period? 3–17
How was the Grand Canyon formed? 1–46
Where may snow-capped mountains be seen? 1–207, 5–443, 452-53, 462

Summary Statement

There are three stages in the building of a folded mountain. First, a great trough is formed and filled with sediment, which sinks deeper and deeper and turns into rock. Then pressure from the sides of the trough crumples and folds the rock. Finally, pressure from below pushes the mass of sedimentary rock up into a mountain.

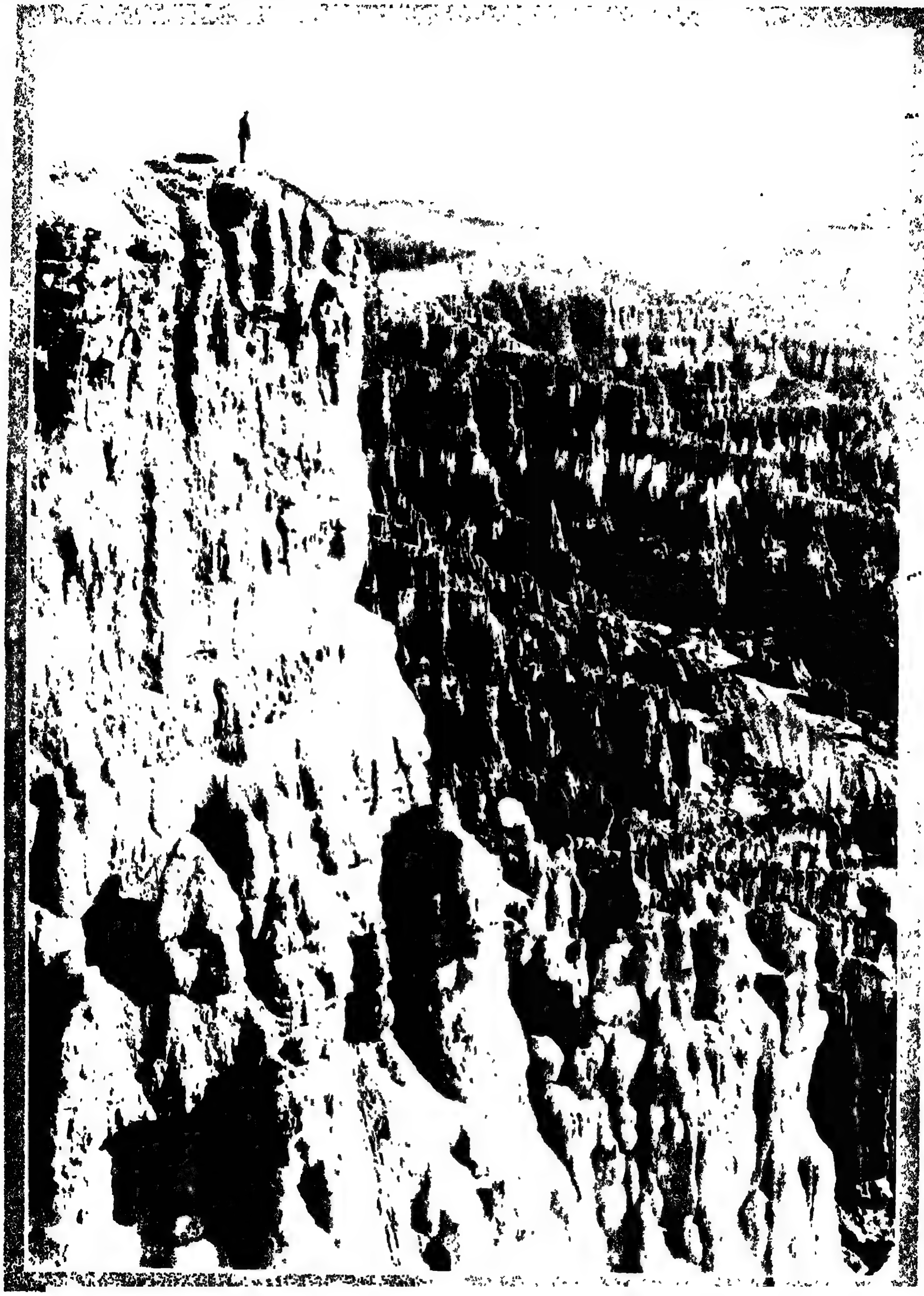


Photo by Salt Lake City C. of C.

The first human beings who gazed upon these steeples and pinnacles in Bryce Canyon, Utah, probably thought of it as the handiwork of some strange, unearthly being. But it is just an example of what Nature can do with water working in flat beds of rather soft material—provided the climate is a dry one. Water trickling through vertical cracks, or "joints," in the rock gradually carved out these slender columns.

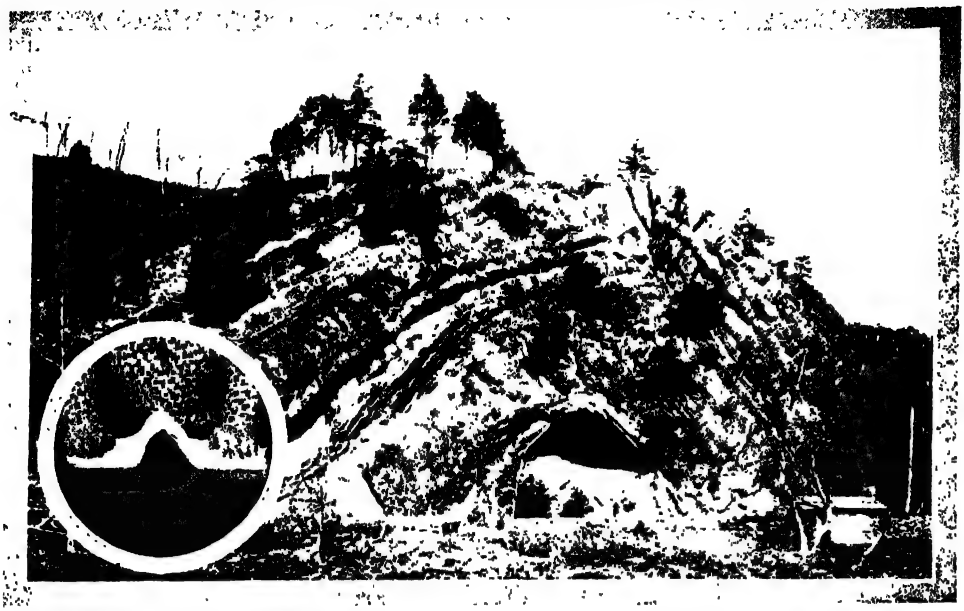


Photo by U. S. Geological Survey

Do you think of a hill as just a hill and a rock as just another rock? When you have read all our chapters on geology you will see things in a landscape you never noticed before. A "cut" in a hill, like the one above, can tell you many things. The rock, you will notice, is sedimentary—that is, water deposited sediment that later became rock. Igneous rock, the kind that is formed from molten material from under the earth's surface, seldom has definite layers; but the material here was laid down in flat beds. It hardened and became rock, and then great pressure from the sides pushed it into a fold. Of course, if you had seen this hill from the top you might not have known what made up its "hump"; so watch for road cuts.

WHAT *a* NEW MOUNTAIN IS LIKE

A Baked Apple Tells Us a Great Deal about What Happened to a Boiling World Millions of Years Ago

WE OFTEN find out about things that are mysterious and far away by looking at the simple ones that are around us all the time. Some of Nature's greatest riddles have been solved in this way. You remember the famous apple which is said to have put Sir Isaac Newton on the track of one of the great secrets of the universe? Let us see if an apple cannot tell us a little more—a little about how the mountains were made long, long ago—ages before there was anyone to see them or any life to live upon them.

First of all, we shall put our apple—smooth and red and firm—into the oven to bake. In a little while the heat causes a number of changes in it. For one thing, the juice inside soon reaches the boiling point and begins to escape as steam; and on account of the loss of juice, the inside begins to shrink. The skin of the apple does not contain much moisture and so does not shrink a great deal. But the body of the apple is no longer large enough to keep the skin in shape; so the skin shrivels and crumples up to fit the mass inside. If we take the apple out of the oven now, we find it covered with ridges and wrinkles.

Now something a little like that may have happened to our big earth long ago, and have wrinkled its skin into hills and valleys. For a long time, indeed, we used to think it was about all that did happen to make our mountains and our ocean beds, and we used to say that all the wrinkles of the earth were just

like the wrinkles on the apple. But we are no longer quite satisfied with the "apple skin theory" for mountains and valleys. For our great mountain ranges do not run helter-skelter all over the earth, like the wrinkles on the apple, which cover the whole surface and run in every direction. On the contrary, the mountains run in certain fairly definite chains.

There are two great mountain chains on earth. One is the American Cordilleras (kôr'dĭl-yā'rä), stretching north and south all the way from Alaska to Cape Horn. The other, which has no good single name, starts in the Pyrenees and stretches eastward through the Alps, the Carpathians, the Caucasus, the Himalayas, and on into the Malay Archipelago. All the other mountain ranges, such as the Appalachians or the Urals, are obviously secondary to these two in extent, in height, and in other features.

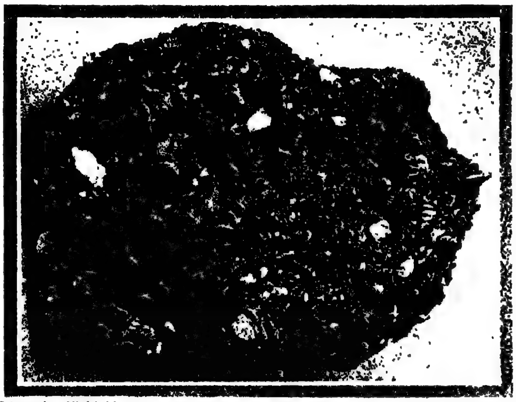


Photo by Field Museum

Where do you suppose this piece of rock came from? It is made almost entirely of tiny bits from the shells of animals that lived in the sea many ages ago. Yet it was found on top of a mountain many feet above the present level of the sea!

There must be some reason for the arrangement of these great chains. As yet we are far from sure what the reason is, though some day we may find out. But even now we can say a good deal as to how the ranges came into being.

A Mystery in Mountain Building

For some reason certain long depressions are formed on the earth's surface—like huge troughs in its skin. The geologist calls them geosynclines (jē'ô-sĭn'klīn). Why these great troughs come into being no one as yet can say. That is the first mystery in mountain building.

Into these troughs the streams bring down sediments from the higher lands all around. Then the added sediment makes the trough sink deeper, some of the "plastic" rock down below being squeezed out by the extra weight above. As the trough goes on sinking, there is room for still more sediment, and so the process may go on until there is a great depth of sediment in the trough—perhaps as much as 40,000 feet in the Appalachian geosyncline. Such a sinking however, can hardly be due to the weight of sediment alone; there must be some other reason for it, as yet largely unknown. But the weight of sediment above is slowly and steadily turning that below into great layers of hard rock.

Usually at some later time, often millions of years later, all this sediment is subjected to enormous forces of pressure at the sides. The pressure squeezes the rock together, crumples it up, and produces the folds and faults and overthrusts that we may long afterward see in mountains. But this pressure, being horizontal, does not raise the rocks up into mountains, though it may crumple them up a good deal like the apple skin. The raising is left for another pressure to do.

Finally another force, this time a vertical one, pushes the masses upward into mountains. This force does not fold or crumple the rocks, but merely lifts the whole enormous mass. What this vertical force is we do not know. It is the second great "mountain mystery." There have of course been guesses at it, but none of them can be called satisfactory.

What we know is that there are three great stages in the building of a folded mountain. First a great trough begins, for reasons unknown, and is filled up with sediment, sinking ever deeper and turning into rock. Then great pressure from the sides crumples and folds the rock. Finally great pressure from below, its cause unknown, pushes the mass up into a mountain. The process goes on

slowly and takes a vast time—a thousand years is only a moment in the life of a mountain. For instance, the Appalachian trough seems to have begun gathering sediment about 500 million years ago; this continued for some 300 million years. Then it was folded; and it was raised to its present height only about 20 million years ago.

Even though oysters may be dumb creatures, it was these silent little beings that first managed to tell us how mountains were made. Over two thousand years ago a wise old Greek named Xenophanes (zē-nŏf′ȧ [illegible]) discovered that certain rocks on mountain tops had oyster shells hidden deep down inside them. He knew well enough that the oysters could never have climbed up the mountains, so he decided that the mountains must once have been beneath the sea. Since his day many learned men have spent their lives studying the earth and its formations, and all of them agree that many mountains have been heaved up out of the ocean. It will also explain the age-old beaches that we still find on mountain peaks, with the pebbles all sorted and arranged according to their sizes, just as they are to-day upon the seashore. Sometimes these ancient beaches are hundreds of miles inland.

This is the "Pillar of Hercules," one of the sights of Oregon. It was once a great rock mountain, but water and wind have had their way with it, and this is all there is left.

We are so likely to think of mountain making only as a thing of long ago that we may be surprised to know it still goes on to-day. A sizable upheaval has actually been measured in Sweden. Rocks that had been marked in 1792 were found, a hundred years later, to have risen three feet. Indeed, it is startlingly true that "quite recently" there were no Rocky Mountains. Of course you must understand that we are speaking of geologic time, which is measured in millions of years. Old Mother Earth would say the Rockies were formed only year before last, when she decided on a slow uplifting of the region of which they are a part.

The "everlasting hills" do not last forever; they come and go. The bottom of the sea is raised up to make a mountain, and later it may once more become the bottom of the sea. In the words of a great Hebrew poet: "Every valley shall be exalted, and every mountain and hill shall be made low." But the change is unhurried. It is a few million years since the Rockies were uplifted. The Appalachians are still older, and were once much higher than they are to-day. Since their first uplifting they have probably been worn down almost to sea level and raised up again.

The Work of the Busy Streams

As you must know, the brooks and rivers are constantly at work wearing away the surface of the land. They steal more than loose sand and soil; their busy fingers wrench away bits of the solid rock and carry the booty down to lay it on the ocean's bed. Here it is smoothly packed, layer upon layer; and here, under the weight of all the sediment on top, the soft mud and sand turn to layers of rock. Whenever a mountain is

upheaved, those layers of rock are reared up, slanting or perhaps on edge—or bent or broken—to form the brand-new land.

In the bare sides of a mountain, then, we have a chance to see the giant's bones. Even from a railway train one may often see the different kinds of rock that go to make his skeleton. Here is sandstone, there is limestone, and farther on is shale—all of them made from different kinds of mud and sand that rivers brought to the ocean ages and ages ago. Imagine the patience of Mother Nature! Grain by grain, layer by layer, the gigantic structure was laid down to a depth of many thousands of feet. In this process a century—a thousand years—are like an hour in your life and mine.

How to Tell Where a Mountain Was Made

If there is a great deal of sand in a mountain's side, you may guess that the rocks were made from layers deposited in fairly shallow water near the shore; for rivers, which are the chief carriers of such materials, cannot travel far into the ocean. Gravel embedded in the sandstone is also a sign of rocks made near to land, for stones are never carried far out from the shore.

In some places in the Appalachians the total thickness of such material was many thousands of feet. After a heavy deposit had been made in shallow water, its weight helped the foundation rocks beneath to sink lower. Then another deposit was made, and again the floor of the sea sank. For millions and millions of years the process went on, till the body of the future mountain was made. Then came great compressive forces which bent and folded the strata. Finally, this mass of folded rocks was raised boldly upward. On the sides of the mountain you may see what happened to the layers which had been spread out so smoothly under the waves. There they are—folded and bent and tilted, some of them almost doubled up, in token of the terrific pressure to which the rocks have been subjected.

That was in the giant's infancy. Now, perhaps, he is old. For a mountain can be born, enjoy youth, attain old age, and die, just like you and me. Its birthplace and its grave are in the sea. All through its youth it is gradually being upreared, though already the wind and weather are at work to bring it down. By the time it stops growing, its enemies are hard at work, eating it away. At last old age sets in, when its majestic head is lowered and its mighty face is scarred and wrinkled by a thousand streams. Its death is slow, but in the end its bulk is worn away, and brooks and rivers, whispering pall-bearers, carry it down grain by grain and bury it in the sea.

Sometimes a mountain range comes into being without folding. The layers deposited under the ocean are uplifted gently until they lie horizontally far above the sea. Then the streams cut valleys in this plateau, eating away all of it except a few high ridges, which form our present mountains. The Catskill Mountains in New York were made in this way. It is the industry of thousands of little streams and lusty rivers that accomplished such a vast piece of work.

At other times mountains are formed when molten material bursts through the crust of the earth in volcanoes. In this way the Cascade Mountains were made along the western coast of North America. If the hot interior cannot quite break through, it may crowd up the crust above it into a lofty dome, as it did when the Henry Mountains in Utah were formed. And sometimes a range may be the result of all of these various processes working together.

We can no longer gaze at the mighty mountains, then, without remembering that they are here for only a short stay. Grain by grain the little streams are plucking them away and carrying them down to the sea. Slowly the rain is dissolving their rocky crags and the wind is sweeping off the dust to distant valleys. Little by little the mighty Rockies, Andes, and Alps will disappear, perhaps to be born again millions of years from now.

"The hills are shadows, and they flow
From form to form, and nothing stands;
Like mists they melt, the solid lands;
Like clouds, they shape themselves and go."

Reading Unit
No. 4

THE EVERLASTING HILLS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The Rockies, the ridgepole of the Western World, 1–24
The Japanese pray to Fujiyama, 1–25
The Himalayas, home of the gods, 1 25
What a mountain is, 1–25
Mountain ranges of the United States, 1–25
What a mountain system is, 1–25
What "mesa" means, 1–25
Three thousand miles of mountains in North America, 1 27
Mount McKinley, the highest peak in North America, 1–27
The Sierra Nevadas, the highest range in the United States, 1–27
The aged Appalachians, 1–27
The Andes, the highest peaks in the Western Hemisphere, 1–28
The real mountains of Europe, 1–29
The "roof of the world," 1–29
Africa and her mountains, 1–29
New Zealand's mountains, rivals of the Alps, 1–29

Things to Think About

What relation is there between the Rockies and the Andes?
Are all mountains as high as they used to be?
What islands are really the tops of mountains?
In how many different countries are the Alps found?
What is the connection between the Apennines and the Atlas Mountains?

Picture Hunt

An old volcano covered with snow, 1–24
How men go through mountains, 10–203
How do we know that Mount Everest is young? 5–432
A mountain greatly worn down, 1–21
How did sea shells get into mountains? 1 20

Related Material

What a new mountain is like, 1–19
Mountain building, 1–20-21
How to tell where a mountain was made, 1–22
How her mountains have affected the history of Switzerland, 6–243-44

Summary Statement

The mountain system along the west of North and South America is one of the greatest in the world. On the eastern side of North America the Appalachians stretch from Labrador to Alabama. The mountains of Europe and Asia form a unit. Africa, Australia, and New Zealand are poor in mountains. New Zealand mountains are as high as the Alps.

Portland C. of C.

This lovely peak is Mount Hood, in the Cascade Range in Oregon. In ages long past it was a fiery volcano, but now glaciers cover its slopes, and it wears a mantle of ice and snow even when blossom time comes to the Hood River Valley. It is a favorite with mountain climbers.

The EVERLASTING HILLS

From Earliest Times Men Have Revered Their Mountains, and Have Drawn from Them Livelihood and Shelter

ALONG the western edge of the two great continents that make up our hemisphere, there marches a long procession of mountain giants whose snowy heads are close against the sky. From the outermost tip of Tierra del Fuego (tyĕr'. rä dĕl fwä'gō), far down toward antarctic seas, to the icy reaches of Northern Alaska, they tread upon each other's heels, one of the longest mountain systems in the world. They affect the climate of a large part of our hemisphere, and deep in their flanks hold untold riches of ore and precious stones. Lightning plays about their summits, and from their scarred and wooded sides flow mighty rivers. With impartial hand they divide the waters of the earth's two greatest oceans. They form the ridgepole of our Western world.

Now anyone who has seen the rosy shapes of the Rockies retreating into the distant blue or gazed at the pure radiance of the Swiss Jungfrau (yŏŏng'frou)—or "Virgin"—will not wonder that early men should have looked at their mountains with awe. Here was a god made visible. Within its ample folds they found shelter from the blasts. On its green sides they pastured their flocks, and from its countless rills were born the rivers that watered their fields. Joined hand to hand those towering masses gave a struggling nation effective protection against its enemies and hemmed it in to build up a strong national life.

So we find that Greece, famous for her rich and varied arts, grew up as a group of tiny separate states, each one working out its own particular talent in its own green valley, encircled by the eternal beauty of its hills. And Switzerland, enthroned in the lofty fastnesses of some of the highest mountains in the world, has kept her independence among the warring nations of Europe by steadily refusing to go down and give battle in the plains. Her mountains serve for ramparts and battleships. It is not by accident that mountain folk--Scots, Welsh, Basques, and Swiss—are rugged, fearless, and full of the love of liberty. A life of hardship and of companionship with the sky has made them so.

All this will explain why men have wor-

shiped their mountains and have loved them as they would a dear and powerful friend. We understand why the simple Japanese peasant prays to sacred Fujiyama (fōō'jē-yä'mȧ), surely one of the most beautiful mountains in the world; and why millions of natives in India to-day think of the Himalayas (hĭ-mä'-lȧ-yȧ) as the home of the gods, especially since no man has ever yet scaled Mount Everest, the highest peak in that stupendous range. We are not surprised that the early South American tribes built their temples high in the Andes to be nearer the sun god, source of all life, or that the ancient Persians carried their dead to the mountain tops and left them there in the eternal care of their sun god.

To be sure, it is only lately, as history goes, that men have come to see the beauty in their mountains, as lately as the eighteenth century. But to-dav our poets and artists turn to "the hills" as one of their surest sources of inspiration, and the rest of us, who do workaday work in a workaday world, seek out the sublime calm of the mountains for rest and refreshment.

THE ALTITUDES OF THE GLOBE.
(The elevation at the South Pole, as noted by Scott, was 9,070 feet.)

HIGHEST AND LOWEST CONTINENTAL ALTITUDES.

CONTINENTS.	Highest Point.	Elevation (Ft.)
North America	Mount McKinley, Alaska	20,300
South America	Mount Aconcagua, Chile-Argentina .	22,834
Europe	Mount Elbrus, Caucasus	18,465
Asia	Mount Everest, India China	29,141
Africa	Kibo (Kilimanjaro), Tanganyika Terr	19,710
Australia	Mount Kosciusko, New South Wales	7,328
Antarctica .	Mt. Thorvald Nilson . .	15,400

CONTINENTS.	Lowest Point	Below Sea Level (Ft.)
North America	Death Valley, California	280
South America	Sea level	
Europe	Caspian Sea, Russia	86
Asia	Dead Sea, Palestine	1,290
Africa	Libyan Desert	440
Australia	Lake Eyre, South Australia	38
Antarctica	. . .	. . .

Approximate mean elevation (feet)—North America, 2,000, South America, 1,800, Europe, 980, Asia, 3,000, Africa, 1,900, Australia, 1,000, Antarctic, 6,000

Mount Erebus, an antarctic volcano, is 13,300 feet. Several peaks over 15,000 feet are in the south polar region. Mt Forel, Greenland, 11,500 feet, was climbed to 10,880 feet in June, 1931, by Andrew Stephenson, L R Wager, and Surg Lieut Bingham of the British Air Route Expedition.

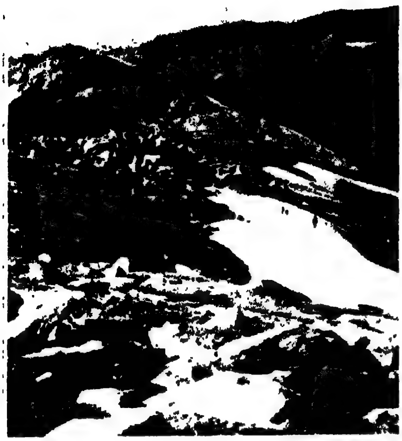
The globe's surface at the North Pole, according to the late Robert E. Peary, is at sea level just water.

What Is a Mountain?

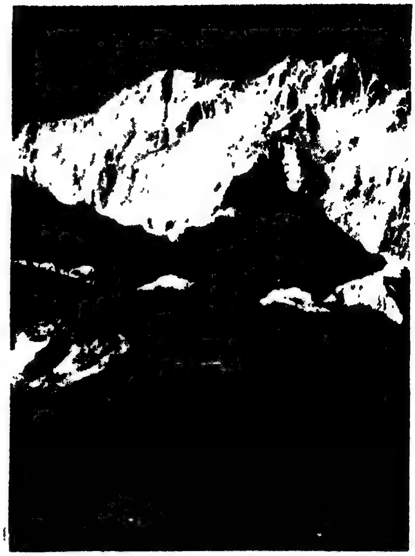
Now what are these gigantic shapes that preside over the destinies of men and nations? It all sounds simple enough. A mountain is merely any unusual elevation on the earth's surface. Some mountains, called peaks, are more or less cone-shaped; if they are extraordinarily slender and sharp, they are called needles; one more or less like a pyramid in shape is known as a horn. The Matterhorn, with a height of 14,780 feet, is one of the famous peaks of the Swiss Alps. But mountains are not usually so simple in shape as this. Instead, they are likely to consist of a series of varied forms, and are often miles in extent. Such elevations are called ridges. The Appalachian (ăp'a-lā'chĭ-ăn) Mountains of our Eastern United States contain a great many ridges.

A group of mountain forms that includes several ridges, with the valleys lying between them and any peaks that may rise within the group, is known as a mountain range. In the Western United States, for example, we have the Wasatch (wô'săch) Range, the Sierra Nevada (sĭ-ĕr'ȧ nē-vä'dȧ) Range, the Cascade Range, and the Coast Range. A number of mountain ranges taken together form a mountain system—such as the Rockies—and a group of mountain systems make up a cordillera (kôr'dĭl-yā'rä). America has a famous cordillera, of which the Rocky Mountains are only a part. It includes all the chains, ranges, and peaks from northernmost Alaska to Cape Horn. The Andes (ăn'dēz) are the South American portion.

Certain mountain forms have special names. As everybody knows, a valley is the depression between ranges of hills. A gorge or canyon differs from a valley in having steeper sides. The crest is the top line of a mountain or range, while a saddle is an exceptionally low point in a crest. A knob is any rounded hill or mountain, especially one that stands alone. A plateau (plȧ-tō') is simply a mountain or a mountain range having a broad top and sometimes gentler slopes. A level plateau that has been worn away till its steep sides rise sheer from the surrounding land surface is often called a "mesa" (mā'sä), especially in the Western United States. The word means "table."



Mount Kosciusko, Australia's highest peak, is only 7,328 feet high, but snow rests on its summit even in the summer. It is in New South Wales.



Mount Everest, the world's highest mountain, is in the Himalayas, between Tibet and Nepal. No one has ever yet scaled that majestic summit.

Mount Aconcagua, the highest peak of South America, is in the Andes between Chile and Argentina. It is an extinct volcano, and was first scaled in 1897.

In 1876 a Russian expedition tried in vain to ascend Mount Elbrus, pictured above. This glacier-covered mountain is the highest summit in the Caucasus.

If this beautiful and awe-inspiring mountain were in Switzerland, it could look down on the Jungfrau and the Matterhorn. It is Mount McKinley in Alaska, the highest peak in all North America.

On other pages we have told how mountains are made and how they are worn down by wind and water. The process has been at work in a great many places. Mountains, even ranges of mountains, are to be found on all the continents. Richard Byrd has recently discovered that tall peaks and extensive mountain chains lie all about the South Pole. Islands of the sea, though small in size, may nevertheless show many traces of mountain formation. Some, such as the Aleutians (ȧ-lū'shăn) off Alaska, many islands of the Japanese empire, and a vast number of those in the East Indies are only the visible peaks of mountains that were sunk in ocean's depths either singly or in chains.

Great Mountains of North America

Some of earth's mightiest mountains, though by no means the highest, are to be found in North America. They fringe the Pacific coast from Southern Mexico to Northern Alaska, a distance of more than three thousand miles. At their greatest width these mountains cover a region more than a thousand miles wide. The highest peak in this vast system is Mount McKinley in Alaska (20,300 feet). Orizaba (ō'rē-sa'bä), an extinct volcano in Mexico, towers upward 18,696 feet; Mount Logan, in Canada, is 19,850 feet. Many peaks are over ten thousand feet. Mt. Whitney, in California, the loftiest mountain in the United States proper, is 14,405 feet high.

Of all the ranges in the United States the Sierra Nevadas, in eastern California, are the highest. Between them and the Rockies, which extend as far west as the Wasatch Mountains, lies a vast plateau—the Great Basin which stretches south into Mexico. It widens till it touches the sea in southern California and reaches into New Mexico on the east. Here in this broad upland are a great many detached ranges running north and south. They are called the Basin Ranges.

The Aged Appalachians

On the eastern side of our continent are the Appalachian Mountains, which stretch from Alabama northward through New

Photo by Sohleman Syndicate

Could anything be more exhilarating than skiing in the shadow of Mont Blanc or climbing to its summit over the glaciers that here show so clearly? Mont Blanc, the highest of the Alps, is in the range that divides France from Italy, and its 15,781 feet can be ascended from both sides.

England, Nova Scotia, and Newfoundland, finally to end as the Laurentian (lô-rĕn′-shĭ-ăn) Highlands in northern Labrador. The Appalachians, old and much worn down, range from about 2,000 to 3,000 feet in height, though the system boasts two considerable peaks—Mount Mitchell in North Carolina (6,684 feet) and Mount Washington in New Hampshire (6,288 feet).

Have You Heard of Loma Tina?

The islands of the Caribbean Sea are in reality only the tops of a chain of mountains that rise in Central America, where they reach an elevation of as much as 13,000 feet. From there they sweep eastward toward the Atlantic Ocean. Famous Loma Tina (lō′mä tē′nä) in Haiti is 10,300 feet high. Since the island of Haiti stands at a spot where the ocean is 27,330 feet deep, we should properly think of Mount Loma Tina as having a height of 37,630 feet taller than any visible mountain in the world.

The Highest Peak in the Americas

Along the western coast of South America, in places rising abruptly from the shore of the Pacific Ocean, stretch the Andes, the southern part of the great American cordillera. The broadest part of the system is in Bolivia, where it reaches a width of some five hundred miles. Northward from there, the Andes fray out and finally reappear as a part of the Antillean (ăn′tĭ-lē′ăn) chain, whose low peaks dot the islands of the Caribbean Sea. In the Andes are the highest peaks on the Western Hemisphere: Aconcagua (ä′kôn-kä′gwä), between Argentina and Chile, 22,834 feet; Sahama (sä-hä′mä), in Bolivia, 22,349 feet; and Mercedario (mĕr′sâ-thä′rē-ō), in Chile, 22,302 feet. All of them are giants.

As in North America, so also toward the eastern side of South America there are ranges of rather low mountains. The Highland of Guiana (gē-än'ȧ), which lies north of Venezuela, has a peak of some 11,000 feet. The Brazilian Highland, in the eastern part of that country, reaches an elevation of about ten thousand feet in places.

The mountains of Europe are more complex than those of any other continent, and can hardly be taken alone. They form a unit with the mountains of Asia. There are low mountains in Ireland, England, and Wales; and Scotland boasts a peak over four thousand feet in height. The Scandinavian Peninsula is also mountainous; the peak Galdhöpiggen, in the central part of Southern Norway, reaches a height of 8,097 feet. But these are Europe's old, worn-out mountains. The real mountains of Europe start in the south of Spain and sweep in a broad eastward-moving curve as far as China. Lying between France and mountainous Spain are the Pyrenees (pĭr'ē-nēz), whose greatest height is 11,165 feet. Eastward are the Alps, lying partly in France, Switzerland, Germany, Austria, and Italy. Many of these peaks are among the highest and most picturesque in the world and certainly they are the most famous. On their western border an arm curves southward and passes through Italy, where they are known as the Apennines (ăp'ĕ-ninz). This range disappears in Sicily only to rise again in Northern Africa as the Atlas Mountains. To the east the Alps disappear in Austria, though the mountain ranges of the Balkan Peninsula that sweep across the islands of the Aegean (ē-jē'ăn) and on into Asia Minor may be thought of as a continuation of them. Encircling the broad plains of Hungary, the Carpathian (kär-pā'thĭ-ăn) Mountains extend eastward into what is properly Asia, where one range of them is known as the Urals (ū'răl). The Carpathians also branch out southeastward to the Black and Caspian seas, where they reappear as the Caucasus (kô'kȧ-sŭs) Mountains, whose highest peak, Mount Elbrus (ĕl'brōōs), reaches 18,465 feet.

The mountains of Asia, the highest and most extensive in the world, are so many and so complex—and so little is known about them—that only the greater systems can be named here. The first great mountain mass of Asia, the Pamir (pä-mēr'), called by the natives "the roof of the world," is situated east of Afghanistan. Three branches extend from it: the Tien Shan (tī-ĕn' shän'), or Mountains of Heaven, reach eastward into Mongolia; the Kuenlun (kwĕn'lōōn') Mountains extend into China; the Himalayas swing southeastward along the northern border of India. This is the greatest collection of mountains in the world, and it includes the world's highest peak—Mount Everest (ĕv'ĕr-ĕst), whose mist-shrouded summit towers 29,141 feet skyward. In recent years several attempts have been made to scale it, but each has been visited by some sort of disaster to the climbing parties.

Most of the many islands large and small that dot the Pacific and Indian oceans to the east and southeast of Asia may be regarded as visible peaks of several submerged ranges of mountains that are a continuation of those on the mainland of Asia. Among these are several large islands—Borneo (bôr'nē-ō), the Philippines, Formosa (fŏr-mō'sȧ), the Japanese Islands, Kamchatka (kăm-chăt'kȧ), the East Indies, and New Guinea (gĭn'ĭ). Many of these islands have volcanoes, and some have peaks more than ten thousand feet high.

Despite the vast extent of Africa, the continent is poor in mountains. Almost the whole of it is a plateau. Besides the Atlas Mountains of the northwest, in places over 14,000 feet high, there are only the tiny Cape Mountains of South Africa and some volcanic cones in the east central part of the continent. The highest of these are the Ruwenzori (rōō'wĕn-zō'rē) Mountains, 16,750 feet; Kenya (kĕn'yȧ), 17,198 feet; and Kilimanjaro (kĭl'ē-män-jä'rō), the highest peak on the continent, with a height of 19,710 feet.

Even in distant Australia and New Zealand there are mountain peaks worth noting. The highest in Australia is Mount Kosciusko (kŏs'ĭ-ŭs'kō), 7,328 feet; it forms part of a low range in the eastern part of the continent. In New Zealand, on the contrary, the mountains rival the Swiss Alps in height and grandeur. The tallest is Mount Cook, which reaches 12,349 feet.

Reading Unit No. 5

THE FIERY FURNACE UNDER OUR FEET

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How thick is the earth's crust? 1–31

How far has man penetrated into the earth? 1–31

When does a volcano erupt? 1–31

Of what does the inside of the earth consist? 1–32

What is a geyser? 1–32

How does the temperature change as one goes down into a mine? 1–32

How are geysers and volcanoes alike? 1–34

Where are geysers found? 1–36

Things to Think About

What difference would it make in the weight of the earth if its interior were composed of the same substances as its crust?

How does the existence of volcanoes affect geysers?

What would happen if the pressure of the earth's crust upon the interior were removed?

Why does not the earth's crust collapse?

Picture Hunt

How does the temperature below the surface of the earth change at different depths? 1–32

How often does "Old Faithful" shoot a column of water into the air? 1–33

How does a geyser work? 1–34

Related Material

How does man use the energy of geysers? 1–344

Which Atlantic islands were formed by volcanoes? 6–489–91

What has been the effect of volcanoes upon history? 5–257, 258, 13–53

What plants grow in volcanic craters? 2–258

What caves have been formed by volcanoes? 1–86

How are underground streams related to geysers? 1–344

Practical Applications

What is done to reduce the temperature in deep mines? 1–32, 383

How have geysers been put to work? 1–344

Leisure-time Activities

PROJECT NO. 1: Make a cross-section model or chart of the temperatures below the earth's surface, 1–32

PROJECT NO. 2: Make a model or chart of a geyser, 1–34

Summary Statement

The hot nickel-iron interior of the earth is covered by a crust of rock that is very thin in comparison with the earth's diameter.

People have dug deep wells and mines into the earth, but they have come nowhere near piercing its crust. Yet this crust itself, in proportion to the total size of the earth, is thinner than an eggshell!

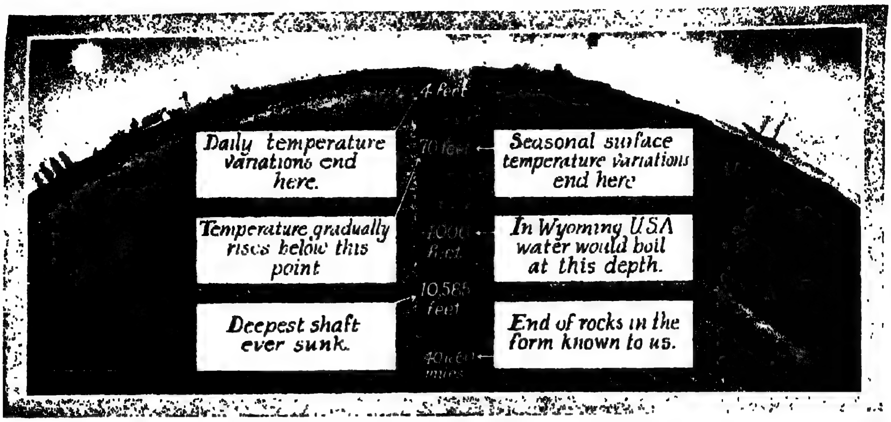
The FIERY FURNACE *under* OUR FEET

Nearly All the Earth Is Still Red-hot, and Sometimes It Manages to Boil Over

HAVE you ever carried a dozen eggs home from the grocery? If you had them in a paper bag, you took great pains not to jar them or give them a blow, and when you got home you set them down very gently to avoid breaking them. "Thin as an eggshell" is almost a proverb.

Now in proportion to the size of the whole earth, the crust around it on which we live so safely is only half as thick as an eggshell. For though it is probably about sixty miles deep, the great globe which it covers is about eight thousand miles through—while an egg is only two inches! It is true that we have no way of knowing just how thick the crust of the earth is, for the deepest hole that we have ever dug is very shallow in comparison; we have never gone down quite so far as two miles, though we have come very near to that in an oil well in California. But scientists can find things out in a way that seems almost like magic to you and me.

Perhaps you may ask what keeps so thin a crust from caving in. It does tremble a good deal—when we have earthquakes—and from time to time the inside bursts through—as when we have volcanoes. But it cannot cave in, because the inside is very firm—far firmer than steel. The pressure of all the miles of rock on top keeps the interior rigid in spite of the fact that it is hot enough to melt. Wherever a substance is heated, it expands—or grows larger. But the hot mass inside the earth is pressed so tightly together that it cannot expand. It has no room to melt, except when some small part of it can find a weak spot in the crust and burst forth as a volcano.



This is what man has learned from the deep pits he has dug into the earth. If you go below a depth of four or five feet, you will find that daily heat or cold will no longer affect the rocks. At a depth of seventy feet below the surface, you will find the temperature unaffected by the heat of summer and the cold of winter. Below that depth, the temperature will show a marked increase as you go down. Since the rate of increase varies, water will boil at different depths in different parts of the world.

Scientists think that the solid core is made of metal, for when they learned how to weigh the earth they found that it was a great deal heavier than it would be if it were all made of the stuff we see in the crust. Indeed, its actual weight is just what it would be if it were nearly all iron, or iron with a little nickel. Then, too, the waves from an earthquake travel through the core at the high speed which they would be sure to have if they were traveling through nickel-iron. For instruments have been invented to measure the speed of a quake as it travels from place to place; and it has been found that waves passing only along the loose crust go a good deal more slowly than those which pass through the metal core.

How Scientists Prove Their Theories

But how, you say, can we know that the center is hot if no one has ever been there?

There are various ways, for scientists never risk a guess without a very good reason. One way is to take the temperature of the earth at different depths as far down as we can go. Professor Agassiz (ăg'á-sē) did this in a deep mine and found that at 3,000 feet down the thermometer showed 99 degrees Fahrenheit (fä'rĕn-hīt), but that at 3,645 feet it stood at 107 degrees. Taking an average for different depths, he found that the temperature rose about one degree for every hundred feet he went down. A hundred miles down, at this rate, it would be over a thousand degrees. One hardly dares imagine the heat at the center, four thousand miles below the surface.

The Telltale Teakettle

But there are other signs that the center of the earth is hot. Here and there we find springs of hot water coming to the surface. Certain of them are called geysers (gī'zẽr), from an Icelandic word meaning "to gush out"—for there are two well-known hot springs in Iceland, the Great Geyser and the Little Geyser. The climate there is so cold that one is a bit surprised to find such springs of boiling water; but they boil up from far below the earth's crust, where it is always hot.

All geysers are much alike. A great well, or "chimney," comes up from the inside of the earth and opens into a large basin on the surface. This is the spout. Hot water from the earth's vast inner furnace comes up the chimney to the surface and fills the basin, which in the Great Geyser measures as much as sixty feet across. For in its long journey underground the intensely hot water dissolved away enough materials in the rock through which it flowed to make itself a basin

Photo by C. B. & Q. Ry.

This is "Old Faithful," one of the most famous of the geysers of Yellowstone National Park. Its fame—and its name—came from the fact that people could count upon it to shoot its dazzling fountain of water high into the air every sixty-five minutes. But now its period of eruption has become irregular. People often have to wait a half hour more than they expected to see the great fountain in action.

at the top, where the minerals were deposited.

Water standing in the basin gradually gets hotter and hotter and finally comes to a boil. It is heated from below by the great column of water which is still rising, and which is well above the boiling point but cannot burst into steam because of the great weight of the water in the chimney and basin above it. Occasionally the water down in the earth gives off a gigantic rumble—the teakettle is beginning to sing. At last it gets so hot that it can be pent up no longer. A little steam is formed. This lifts the column of water, causing some of it in the basin to overflow, and hence lowers the pressure all the way down the chimney. The water in the chimney—especially in the lower part—is so hot that it is ready to flash into steam at the slightest release of pressure. When the release comes, in the way we have shown, the whole column in the lower part of the chimney can flash into steam at once, with a great explosion. The explosion hurls the water above it high into the air. This empties the basin. Some of the water that was blown up falls back down the chimney, but the water below is still boiling too hard to be confined again. With another loud report it hurls the water out in another—or "secondary"—explosion. By this time the water in the chimney is getting cooler, and the chimney is partly emptied. So the geyser rests a bit while the water flows up again and rises to the top of the basin. Then it begins to boil anew and the whole story is repeated.

The diagram above shows you how a geyser works. First there must be a tube or crack in the earth, which is probably crooked or slightly obstructed in some way. This tube leads toward a mass of hot rock which most people believe to be uncooled lava. Ground water—enough to keep filling the tube as it is emptied by eruptions—seeps in and is heated. Now if the tube were short or unobstructed, the water would just bubble and boil away quietly as it does in many boiling springs. But something keeps the heat from circulating freely through the whole column of water, and so the lower portion reaches the boiling point first, and is kept from boiling over by the cooler water above. But if a little of this boiling water expands into steam, then the whole column will be raised and some of the water above will overflow. This relieves the pressure on the water at the boiling point. It immediately turns into steam and shoots the water column above it high into the air. You will find something of the same principle at work in your teakettle at home.

One of the smaller geysers in Iceland is unusually interesting because we may look down its chimney and see the water boiling. But if we try to choke it by throwing in rubbish, the water will grow angry at being pent up and, when enough steam has gathered, will hurl the rubbish sixty feet or so into the air. Great clouds of steam will rise with it.

Geysers are heirs to volcanoes and are found only in places where volcanoes have been at work fairly recently. We know the water must be heated very far down in the earth, for in Yellowstone Park there are a large number of geysers close to the lake, where the rocks are certainly kept cool far down below the surface by the cold water from the lake that works its way into the earth.

The most picturesque and wonderful geysers in the world are found in Yellowstone Park. There are no less than fifty along the

Photo by C. B. & Q. Ry.

The Yellowstone has many hot springs or pools—some with antics all their own. Above is "Handkerchief Pool," which had the amusing habit of sucking down any bit of cloth thrown into it—and always returning the article some time later! Now, unfortunately, it seems to have grown tired of the performance.

Photo by High Commissioner for New Zealand

There is no use putting a kettle on the stove if you live in this region! At any rate these Maori women are probably of that opinion, for they have found Nature's own steam cooker—a hole in ground from which steam is issuing. This particular steam hole is in New Zealand.

Photo by Govt. of New Zealand

One of the great geyser districts of the world is in New Zealand. The geysers are not so spectacular as those of the Yellowstone, but the district is beautiful, none the less. It has a great number of boiling pits, steam fountains, and mud volcanoes; and often fantastic shapes have been built up from the deposits of the boiling waters. Above is Frying Pan Flat Geyser, in New Zealand.

Fire Hole River alone—all of them busy throwing up jets of water, sometimes as high as 250 feet. Let us pay them a visit. Our guide explains that the purpose in setting aside this great natural park is to preserve a part of the old American wilderness, that it may always remain unspoiled by civilization. The tract is so large that we must spend several days in a motor if we are to see it all. To say that it covers two million acres does not, perhaps, give much idea of its size. When we know that it is sixty-two miles long and fifty-four miles wide, we realize what a large park it is. There is wild life everywhere, from gentle little animals that pause just long enough for us to take their pictures, to all kinds of big game, such as deer and buffalo. Bears that are so tame they are a nuisance insist that we must be carrying lumps of sugar. There are many accidents because people feed them by hand.

There are numerous mineral springs, such as the Apollinaris (ȧ-pŏl'ĭ-nā'rĭs) Spring and the Iron Spring, where we may sip the waters. At one spot is an enormous lake of great depth; and in the distance are the Rockies. The coloring of the Yellowstone Canyon is an amazing sight. Its gorge is more than a thousand feet deep—a gigantic "V" that measures two thousand feet across at the top and only two hundred feet at the bottom.

But it was the geysers that we came to see; and there are plenty of them. There is "Old Faithful," flinging 150 feet into the air a jet of boiling water 6 feet in diameter. The air is filled with steam, as from an enormous kettle. Other smaller geysers claim our attention, and when we look again we find that Old Faithful has ceased action. We expect to see it begin at once; but our guide assures us that it will be quiet for more than an hour. It used to spout regularly every sixty-five minutes, but now it is getting lazy and is not so punctual. It is still a magnificent sight, however.

Geysers are found in various places, but it is in the Yellowstone, in Iceland, and in New Zealand that they are seen at their best. The most powerful of all was the Black Geyser in New Zealand. It was first seen in action as recently as 1901, when it threw up such a quantity of mud and stones that its waters looked like ink. Sometimes it took a long rest, and then suddenly threw the water to the enormous height of sixteen hundred feet. But this geyser did not live long; it was extinct by 1905. Some of the other hot springs in New Zealand are put to a delightful use. They feed open-air swimming pools, where one may bathe in the health-giving mineral water, which is often as hot as one can comfortably bear.

Reading Unit No. 6

HOW THE EARTH GOT ITS CRUST

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the work of a geologist? 1–39

What is a fossil? 1–39

What is the thickness of the earth's crust? 1–40

Which rocks first formed on the earth? 1–40

Why did rock form on the surface of the earth? 1–40

Which were the first sedimentary rocks? 1–41

Things to Think About

What would have happened to the earth if rocks had been heavier than metals?

What would the earth be like if water had not changed the rocks?

What would be the effect of removing a large area of the earth's crust?

What will eventually happen to present-day mountains?

Picture Hunt

How were the sentinels in the Garden of the Gods formed? 1–39

Why are the dikes made of hard rocks? 1–38

What would you find if you dug sixty miles into the earth? 1–40

Why can some rocks bend? 1–41

Related Material

How do rocks tell us the history of the earth? 1–18-21, 53-54, 62, 69, 94, 3–1-6

How is stone used in architecture and sculpture? 11–19, 25, 98, 375, 379, 409

What is the result of a scarcity of stone in Mesopotamia? 11–24, 26

How do rocks tell us the story of glacier? 1–60

How do bacteria destroy rock? 2–20

How do animals and plants form rock? 1–51-54

What kind of rock do ocean floors cover? 1–67

Practical Applications

Why do the bricks of our houses wear away? 1–41

How do we use the forces of nature to conquer rocks? 1–41

How do rocks indicate earthquake regions? 1–81

Where do we get salt? 1–44

Summary Statement

Igneous rock means rock that was "made by fire." It was earth's first crust, and from it came the soil and rocks we have to-day.

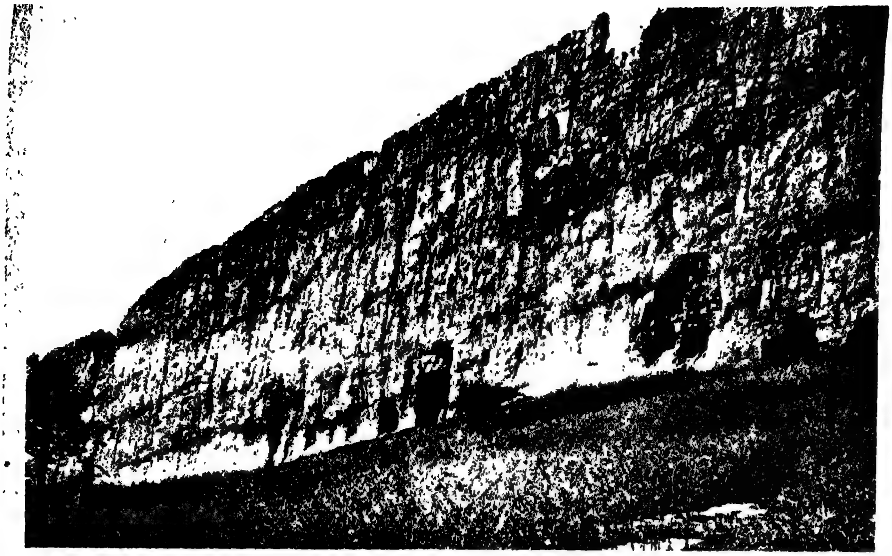


Photo by U. S. Geological Survey

This is the Great Dike of Colorado, which, as molten lava, was pushed into a crack in sedimentary beds which formed a sort of mould for it. The sedimentary rock was softer and wore away, leaving the hard wall of igneous rock still standing. Notice the lines the stratified "mould" left upon its sides.

Photo by Union Pacific Ry.

In this view of Bryce Canyon you can see how layers of sediment, piled one above the other, are gradually being worn away—the harder layers often forming protective caps for those below.

to by Northern Pacific Ry

These strange sentinels stand in the Garden of the Gods, in Colorado. Once upon a time they lay in horizontal beds. Then great movements of the earth's crust hoisted the layers up until they stood right on end. After that, Nature carved the upreared rock into the fantastic shapes you see here.

HOW *the* EARTH GOT ITS CRUST

What We May Find if We Ever Try to Dig a Hole through to China

A FAMOUS poet tells us there are "sermons in stones." It may be still easier to find tales of adventure in them. For the elderly rocks had many an exciting time in the days of their youth. Pebbles along the seashore and stones by the side of the road could all tell us a great deal about the history of the earth. Each of them is thousands—many may be millions of years old; everything else we see in the world is young beside them. Hidden within them is many a thrilling tale of how the world grew.

The learned men who read the fascinating tale are called geologists (jē-ŏl′ō-jĭst), a word which comes from the Greek and means "one who studies the science of the earth." But the records of the rocks are open to anyone who will look at them. You may hold in your hand a stone that was made millions of years ago, and if you are lucky you may find the fossil (fŏs′ĭl) of some creature which lived ages before man appeared on earth. For a fossil is nothing but a skeleton walled up in stone. But that is another story! It is the building up of the earth's thin crust that interests us at the moment.

First of all, let us see what the crust is made of. What is it that stands between us and the fiery furnace into which, without it, we should all sink? The best way to find out is to dig a hole straight down into the

earth. Of course, it must be done in our imagination only. Really to dig it would cost so many millions of dollars that no one has ever tried.

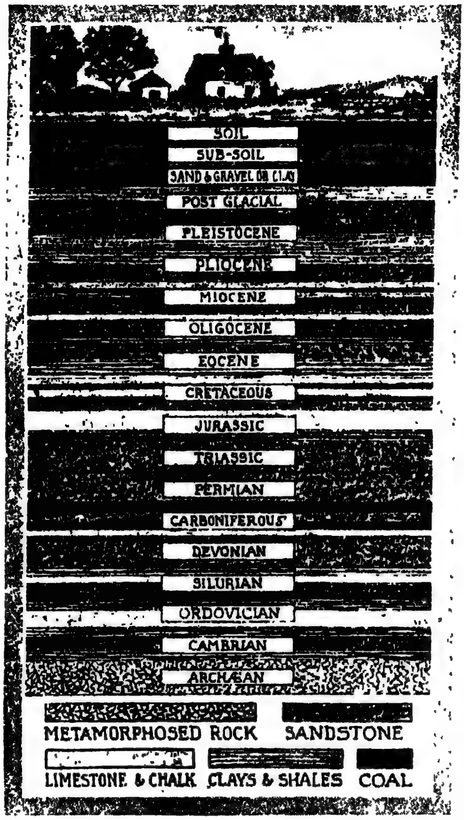
We shall have no trouble at the start. First of all comes a thin layer of soil. Next we shall find, in most places, a layer of subsoil. In this the solid rock is decaying into bits. In one place we shall find gravel, in another sand, and in still another clay. If the bits of stone are so tiny as to be smaller than peas, we call them sand—or if yet more tiny, clay; but if they are somewhere between peas and golf balls, we call them gravel. We shall find them even bigger—as large as small melons or larger—and then we name them boulders. At last, below the subsoil, we shall come to solid rock. This has never been broken up into boulders or sand or gravel.

Somewhere about sixty miles down we may expect to reach the bottom of the earth's crust. We are not sure what we shall find next, but geologists believe that the material just below is so hot that if it were free it would melt. Since it has all the weight of miles of rock on top of it, there is no chance of its melting and running, no matter how hot it may get. It is pressed down with such force on every side that it is kept perfectly rigid.

Since the earth is nearly eight thousand miles through, its rocky crust is about as thin, in proportion, as a coat of rust on a metal door knob. The soil itself is much thinner still. Yet if it were not for the soil, what a barren waste our earth would be!

To find out where this thin but precious layer came from, we must go back to the very first rocks that were formed. The first shell which certain scientists believe hardened round the earth was made of igneous (ĭg′nē-ŭs) rock—which means that it was "made in fire." Geologists often refer to it as the primary rock, "the first to be formed." The stuff out of which primary rock was made once existed as impurities, or "slag," in the molten iron which was later imprisoned inside the earth. Since it was lighter than iron, it rose to the top of the seething mass, cooled, and formed a layer of rock. This process kept on for millions of years. Slowly the earth was completely incased in a coat of igneous rock.

It is well to remember that all the other rocks, and the soil



Geologists have divided the earth's history into eras, periods, and epochs, many of which are still further subdivided. Below is a table listing the main divisions, and above is a diagram showing the layers of sedimentary rock which are typical of each. Igneous rocks are not shown.

Cenozoic era	**Quaternary period**	**Recent or Human epoch**
		Pleistocene or Glacial epoch
	Tertiary period	**Pliocene epoch**
		Miocene epoch
		Oligocene epoch
		Eocene epoch
Mesozoic era	**Cretaceous period**	
	Jurassic period	
	Triassic period	
Paleozoic era	**Permian period**	
	Carboniferous	**Pennsylvanian period**
		Mississippian period
	Devonian period	
	Silurian period	
	Ordovician period	
	Cambrian period	
Proterozoic era	**Keweenawan period**	
	Huronian period	
Archeozoic era	**Archean complex**	

as well, are children of the primary rocks.

The earth's first thin crust was extremely hot, so hot that it must instantly have turned the rain to steam—like drops of water falling on a hot stove. But as the crust cooled, the water could stay on the surface. There it formed rivulets and channels on the slopes, and pools in the hollows. The surface of the earth at this time was probably covered with materials thrown up out of volcanoes, especially with volcanic ash. The rains and the resulting small streams could carry this off very easily, taking it down into the hollows and basins. There it was formed into rock—the first sedimentary rock ever made. Since this rock is of the same material as the parent igneous rock, however, it is very hard, if not impossible, to tell one from the other. After the volcanic stuff had been carried away, the rains and streams began their attack on the primary rock itself.

We must not suppose that the primary rocks suddenly crumbled away under the pounding rain. Millions of years are needed to tear down a mountain. Under the glare of the sun, the rocks in the daytime grow hot—and heated rocks expand, or swell. At night, when the sun has set, they cool off and contract—or shrink. The constant swelling and shrinking, with the help of various chemicals in the air, slowly loosen some of their tiny grains, which are finally torn away by the wind and rain. Try rubbing your hand over a brick that has long been exposed to the weather; thousands of little particles will fall to the ground. The powerful teeth of sun and wind and rain have been at work, nibbling away at the surface of the brick.

And Jack Frost also takes a hand. When the rocks are warm and swollen, the rain seeps into their tiny pores and does not dry out easily. If it freezes there, it is certain to crack even the firmest rock, for freezing water expands. Then the wind and rain fall upon the loosened particles and bear them away as sand or dust, later to form soil.

Strangely enough, heat has much the same effect as frost. It expands the rocks until they crack and fall apart. There is a story that Hannibal of Carthage, when he crossed the Alps on his way to Italy, broke up great stones in his way by lighting fires beneath them. In times gone by, fire was sometimes used in mines to crack the rock.

So under the attacks of wind and rain and sun and frost, the solid ramparts of the Rockies may some day be fertile soil for fields of grain. You and I will never see it. But our lives are only an instant in the earth's long span of years. They are like the racing seconds that a clock ticks off. The patient hour hand, traveling so slowly that we cannot see it move, tells out the hours for anyone who will take time to see. And so the little stream that sings its way from mountain top to valley is carrying off the towering mass to empty it into the sea. But we should have to stay a million years if we would see the work brought to an end.

Have you ever seen a slab of rock that would bend if you pressed on it or stood it on end? If you have, it was probably flexible sandstone, a fine-grained rock containing tiny scales of mica. A slab of flexible sandstone is shown in the picture to the right.

Photo by the National Museum

Some people think that the sandstone will bend because of the bits of flexible mica it contains. Others say that it is because the tiny grains of sand in the porous rock are interlocked—that is, they are connected with hingelike joints which allow the grains to move but not to fall apart.

Reading Unit No. 7

THE GREAT AGE OF MOTHER EARTH

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How old is the earth? 1–43
Why is Great Salt Lake in Utah drying up? 1–44
Where does salt come from? 1–44
What is salt? 1–44
How does water dissolve rock? 1–44
How large was Great Salt Lake thousands of years ago? 1–44
How much salt does Great Salt Lake contain? 1–44
Why does the Dead Sea contain no animal life? 1–44

Things to Think About

What will eventually happen to the Dead Sea and to Great Salt Lake?
Why will the ocean become more and more salty?
Why does the Caspian Sea remain the same size in spite of evaporation?

Picture Hunt

How is the salt of Great Salt Lake gathered? 1–44
How is underground salt mined? 1 409-10

Related Material

Why is radium important in medicine? 9–426
When did life begin on the earth? 3–6, 9
How are rock bridges formed? 1–53
Why are animals attracted by salt? 9–414
How do savages get their salt? 9–413
How do the Bedouins get their salt? 9–413

Practical Applications

Why is the salt in the earth necessary to life? 9–413
How is radium used to conquer disease? 9–426

Summary Statement

Scientists estimate the age of the earth by studying the cooling rate of rock, and by measuring the extent to which radium in the earth has changed into lead.

The GREAT AGE *of* MOTHER EARTH

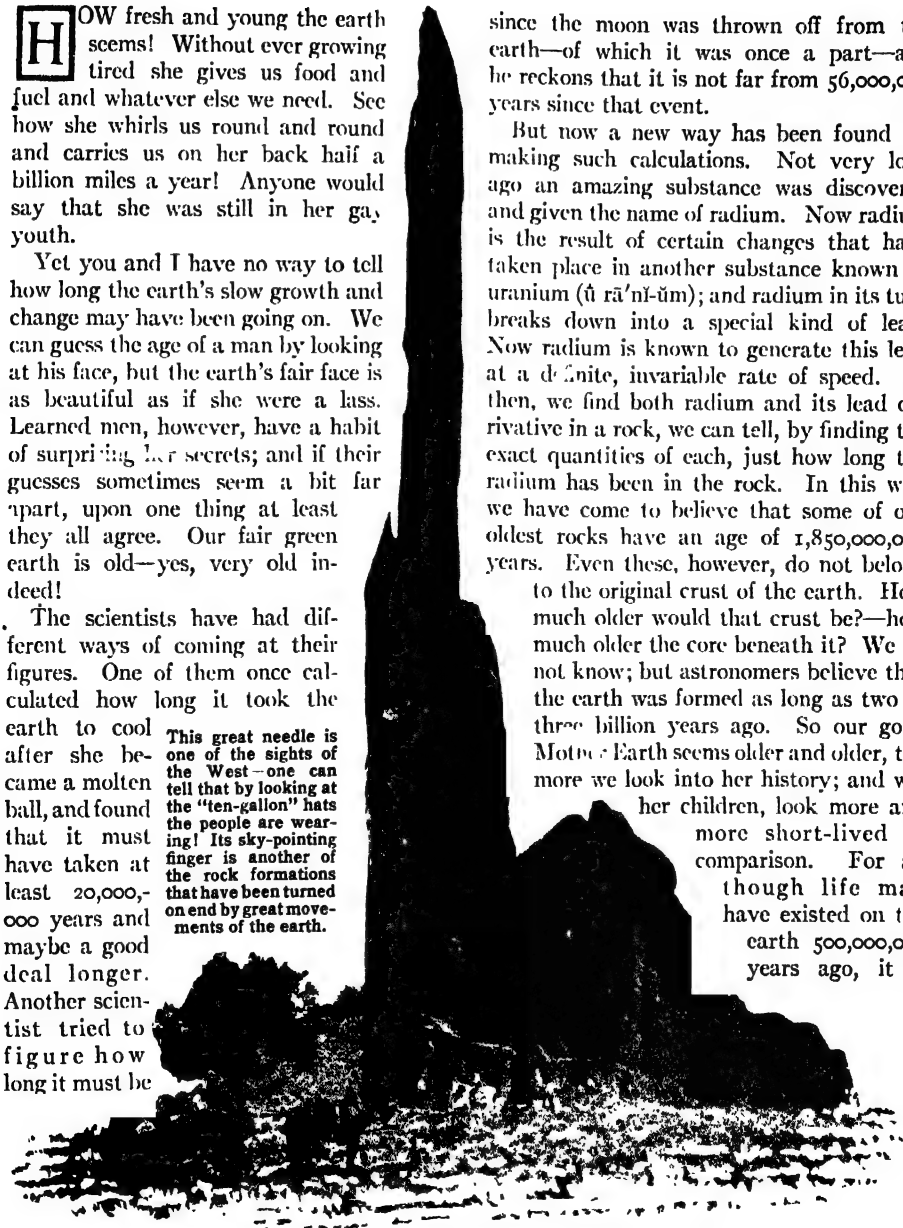
Although Still Young as Ages Go in the Sky, She Has Already Seen Millions of Centuries

HOW fresh and young the earth seems! Without ever growing tired she gives us food and fuel and whatever else we need. See how she whirls us round and round and carries us on her back half a billion miles a year! Anyone would say that she was still in her gay youth.

Yet you and I have no way to tell how long the earth's slow growth and change may have been going on. We can guess the age of a man by looking at his face, but the earth's fair face is as beautiful as if she were a lass. Learned men, however, have a habit of surprising her secrets; and if their guesses sometimes seem a bit far apart, upon one thing at least they all agree. Our fair green earth is old—yes, very old indeed!

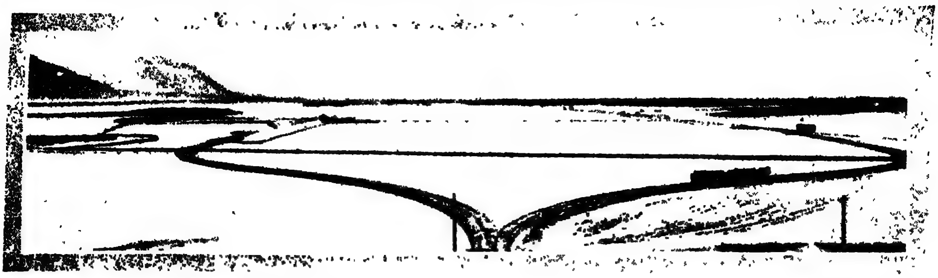
The scientists have had different ways of coming at their figures. One of them once calculated how long it took the earth to cool after she became a molten ball, and found that it must have taken at least 20,000,000 years and maybe a good deal longer. Another scientist tried to figure how long it must be since the moon was thrown off from the earth—of which it was once a part—and he reckons that it is not far from 56,000,000 years since that event.

But now a new way has been found for making such calculations. Not very long ago an amazing substance was discovered and given the name of radium. Now radium is the result of certain changes that have taken place in another substance known as uranium (û rā'nĭ-ŭm); and radium in its turn breaks down into a special kind of lead. Now radium is known to generate this lead at a definite, invariable rate of speed. If, then, we find both radium and its lead derivative in a rock, we can tell, by finding the exact quantities of each, just how long the radium has been in the rock. In this way we have come to believe that some of our oldest rocks have an age of 1,850,000,000 years. Even these, however, do not belong to the original crust of the earth. How much older would that crust be?—how much older the core beneath it? We do not know; but astronomers believe that the earth was formed as long as two or three billion years ago. So our good Mother Earth seems older and older, the more we look into her history; and we, her children, look more and more short-lived in comparison. For although life may have existed on the earth 500,000,000 years ago, it is



This great needle is one of the sights of the West—one can tell that by looking at the "ten-gallon" hats the people are wearing! Its sky-pointing finger is another of the rock formations that have been turned on end by great movements of the earth.

Photo by Atchison, Topeka, and Santa Fe Ry



Once upon a time—way back in the Ice Age, when the presence of great sheets of ice gave the United States a much wetter climate than we have to-day—Great Salt Lake in Utah was ten times its present size. But as the climate grew drier, the lake grew smaller and smaller. It has no outlet, and during the ages the streams had brought in tons of salt. When the water in the lake was gradually evaporated, this salt was left behind in great deposits. Above, people are busily harvesting it to-day.

probably only 1,000,000 years since man put in an appearance. How interesting if we could have a snapshot of those first forefathers of ours!

Scientists have even tried to calculate how long it must have taken to put all the salt in the sea. But the figures do not add much to the ones already given, and it may be more interesting to ask how the salt got there at all.

Where did the salt come from? There is only one place where it could have been, and that is in the rocks. There salt is formed by the combination of two kinds of atoms—sodium (sō'dĭ-ŭm) and chlorine (klō'rĭn). Then fresh water rains down from the clouds and sinks into the soil or trickles through the rocks. As it creeps along, it dissolves the salt away and carries it into the little rills that run down all the hillsides to make up the rivers. The rivers travel onward and finally find the sea. There the water on the surface is constantly evaporating and leaving its salt behind. So there the salt must stay. Once it has reached the sea, it can never get out again. The ocean must always grow more and more salty.

All rivers and streams contain salt, but it never has a chance to gather in them, for they are constantly carrying it down to dump it into the ocean. It is only when a body of water has no outlet that salt will accumulate. Sometimes, in such a case, the water grows excessively salty. This has happened in the Great Salt Lake of Utah, which is constantly losing great quantities of water by evaporation, for it is spread out over a very large area—some two thousand square miles—but has an average depth of only fifteen feet. This means that the brine is diluted very much less than it would be if the lake were deeper and the sun did not drink up the water so fast. So the lake gets saltier and saltier, and at a much quicker pace than the sea. It is estimated to contain some 400,000,000 tons of salt.

But even then it is not so salty as the Dead Sea in Palestine, another lake that started with fresh water, but had its outlet cut off. Neither plants nor animals can live in its strong brine. It is lower than sea level, but it does not get its salt from sea water draining into it. Its fresh waters were gradually turned to their present saltiness by the constant flowing in of salt-bearing streams that, instead of flowing out again to the sea, were licked up by the burning sun and left their salt behind.

The greatest lake in the world is the Caspian Sea, which has an area of 170,000 square miles and in places is over 3,000 feet deep. It was once a part of the ocean, but was locked in by the lifting up of the land. Its waters have become almost fresh, for it is constantly receiving fresh water from rivers and it has a large outlet to the sea.

Such has been the work of streams! Sand, gravel, salt—rivers are busy carriers and they transport everything they can lay hands on down to the sea. They have helped mightily to shape the earth into the form we know and love so well.

Reading Unit No. 8

A LITTLE STREAM TELLS A STORY

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How did the earth get its water? 1–47-48

Why does the water in the air always return to the earth? 1-48

How did new rocks form? 1–48

At what rate does water dissolve land? 1–48

How does sand erode the land? 1-48-49

How much sediment does the Mississippi River deposit in the Gulf of Mexico daily? 1-49

How do sand and soil become rock? 1–49

What is mud? 1-49

Things to Think About

What part did water play in the formation of the Grand Canyon?

What would ocean water be like if water did not dissolve things?

What would happen to our oceans if the earth's crust reached the temperature of its interior?

How did the formation of water hasten the cooling of the earth?

Picture Hunt

Why do the walls of the Grand Canyon look like steps? 1-46

What is meant by the "youth" of a stream? 1–48

Related Material

How much rain falls on the United States each year? 1-89

How much water is there on the earth? 1–363-64

What is the importance of water to plant life? 2–46, 193, 197

What was water before it formed on the earth? 1-2, 499, 13–3

What land formations are caused by streams? 3–3

What caused the prehistoric reptiles to disappear? 3–48-49

Practical Applications

How does water affect the soil? 1-47-49

How does water add to the beauty of our surroundings? 1-47-49

Why does the harbor at the mouth of a river sometimes become unnavigable? 1–48-49

Leisure-time Activities

PROJECT NO 1: Remove sediment from muddy water, 1–49.

PROJECT NO. 2: Find stones that have been worn smooth by streams.

Summary Statement

When the earth's surface was cool enough, pools of water gathered, flowing into cracks and depressions in the earth's crust. Continual movement of these streams wears away the rock.

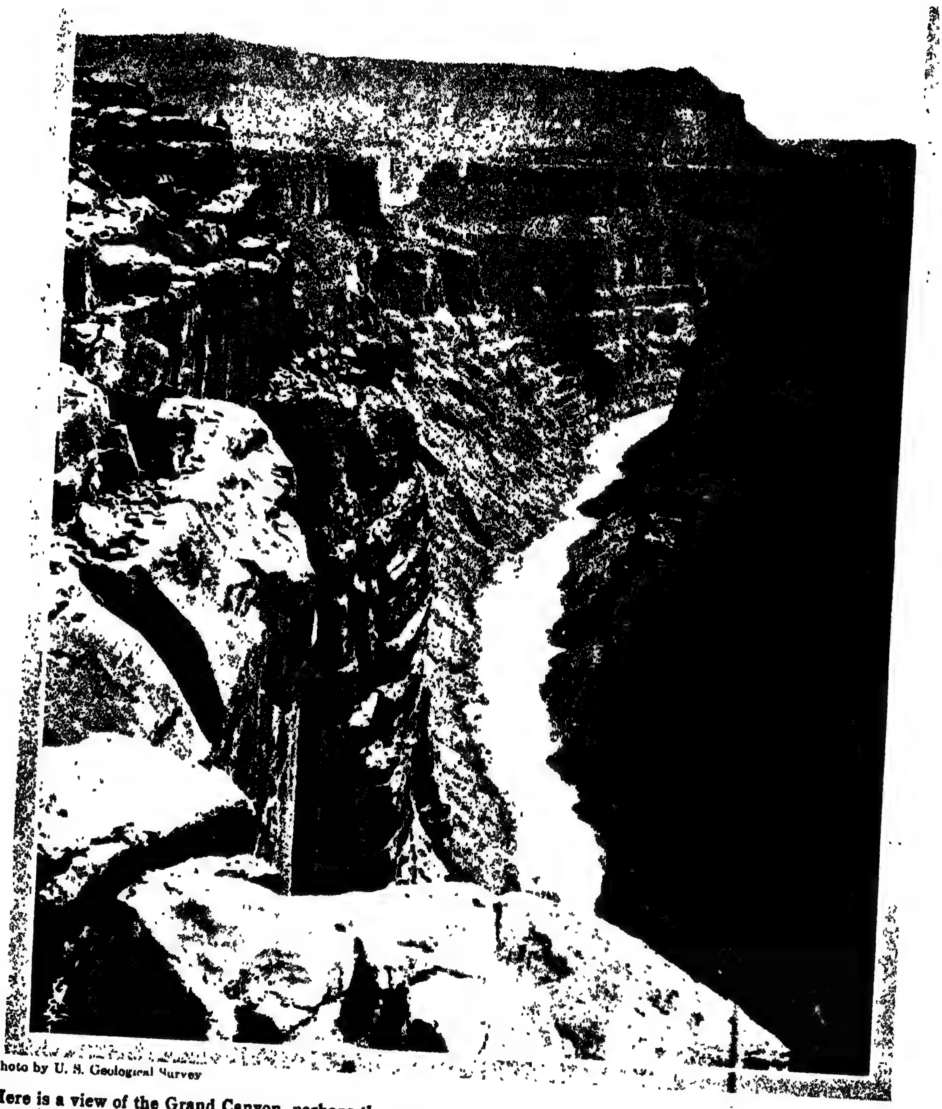


Photo by U. S. Geological Survey

Here is a view of the Grand Canyon, perhaps the most imposing of all of Nature's marvelous works. This tremendous gash is in some places more than a mile deep, and eight to twelve miles wide. It was cut by the Colorado in the high plateau region into which the river descends, swollen by the snow and rains of the Rocky Mountains. Weathering and smaller streams helped it in its work, till now its channel has cut down to the folded rocks of an ancient mountain system. When these mountains slowly sank beneath the sea, masses of sediment that later became rock were piled on top of them. Then the region was elevated in such a way that the flat beds remained practically horizontal. The stream began its cutting, exposing one layer after another—the harder layers forming cliffs and steps, like a giant's stairway.

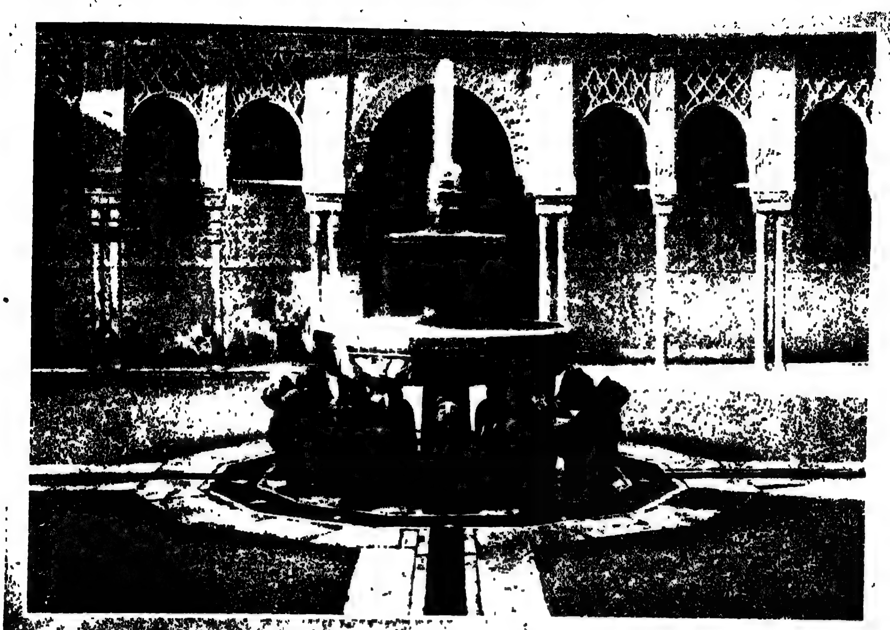


Photo by Au[illegible]

The cave men probably never thought of the beauty of water. They only knew that it was a necessity. But as soon as man learned to build fine houses and cities he began to adorn his courtyards and market places with fountains. Above is the Fountain of the Lions from the Alhambra in Spain.

A LITTLE STREAM TELLS *a* STORY

Have You Ever Talked with a Brook? Perhaps You Do Not Know How! Here Is One Way to Do It

THERE once lived a man who could hear the animals talk. He was a wise old Greek named Aesop (ē'sŏp), and the greatest writer of fables the world has ever seen. In his enchanting tales the animals often speak more wisely than their masters; and their adventures are always worth listening to. If only we could make the hills and valleys and the little rills tell us the story of their long, eventful lives, what an amazing history that would be! Suppose we try! Let us play Aesop and command a little stream to tell us its life story. Come, let us sit down here on this carpet of soft grass in the shade of the ancient elm and let the chattering brook flow by, while we listen to what it has to say.

Its very first sentence is a surprise, for it tells us that it saw us when we took our famous journey on the magic carpet back to the beginning of the world. How could that be? We saw no stream there then.

"No! But I was part of the multitude of tiny electric particles," says the stream. "I lived long before I was made into water; but my recollection of those early times is rather hazy. I have a dim remembrance of being lodged inside the earth, and of escaping in the form of gas. But my only clear impression is one of tremendous heat. I could never tell you how hot it was. Next I remember being part of a gigantic cloud of steam.

"At one time I would be floating high in the air as a cloud, and later would be falling down upon the earth as rain. How hot it was! It did not take me long to rise up and

float once more in the air. This went on and on, till I was tired of it. One thing I did notice was that the earth was getting gradually cooler. I have dim recollections of the formation of the earth's crust, but it came about so slowly that I did not realize what was happening.

"When it finally hardened, the solid crust around the earth acted as a shield to protect me from the hot center. This was a great advantage, for I could now stay on the earth long enough to do some useful work; up to this time I had no sooner arrived than I was shot back into the air as steam.

"I feel confused when I try to recall those early times, but I remember quite clearly what has happened since I became a stream. At first I ran along the cracks on the surface of the earth, where I had fallen in raindrops. In my journeys I managed to tear off tiny fragments from the rocks. You may think I was doing this for mischief, but you know all the good that came of it. I was making a bed in which I might have a permanent home. Oh, yes! I knew I should be lifted up into the air to form clouds again, but I also knew that I should always return as rain.

Photo by Salt Lake City C. of C.

When you see a little stream that comes tumbling down the mountain side, pushing great stones and boulders along its path as it leaps over waterfalls and gurgles in rapids, you may know that that little stream is still in its infancy. For streams have their periods of youth, maturity, and old age, just as people do. Now a stream in its old age is much more sedate. You will find it flowing sluggishly over the wide flat plain it has made, swinging in its bed from side to side until its channel becomes a series of zigzags, or "meanders." But an impetuous torrent like the one above is certainly in its giddy youth.

Little Drops of Water

"I had great ideas of forming a mighty ocean; and the bits of sand I was carrying were going to make new kinds of rock for the young earth's crust.

"You may think these ambitions too high for little drops of water such as I am made of, but I have heard it said that

'Little drops of water,
Little grains of sand,
Make the mighty ocean
And the pleasant land.'

"I can tell you I am proud when I hear that verse; I feel repaid for all the great patience it has taken to keep on with my work day and night, year after year. People have told me that I set them a very good example, and that they wish they were half as patient as I have been. Why, it took me thousands of years to make any visible impression on the earth's hard surface. The particles that I could loosen from the rocks were extremely small, and at the end of a day I had really nothing to show for my labor. Indeed, at the end of a whole year I seemed to have accomplished nothing at all. It was rather disheartening. But when I look at the great rivers and the mighty sea which I helped to form, I am glad that I had the patience to keep on.

"To carry on this great work of making a bed in which I might run, I had no tools except tiny bits of sand to cut away the hard surface of the rock. One thing that helped me and gave me some encouragement was that I got the aid of billions of drops of water from the clouds. When they fell upon my mountain top, they came hurrying down into my stream and made me much more powerful. The crowding and pushing was so great after a rainstorm that I sometimes managed to rip away great stones from the mountain's side.

"Sometimes I could bang one against a hard rock, so that I shattered the stone into little pieces. As I rolled these along, they lost their rough edges and became pebbles. You can see how smooth I have worn them. Just look at them on the seashore where I helped to carry them long ago.

The Mighty Mississippi

"I can wear away the rocks only very slowly, but you must remember that I am not the only stream at work. Many of us empty into our big brothers, the rivers, where the accumulation of sand is enormous. You will be surprised to hear that the Mississippi empties 7,500,000,000 cubic feet of stuff into the Gulf of Mexico every day. The river Thames, in England, carries down five million tons of material every year. Although you cannot realize what five million tons is, you can see that it is an enormous quantity.

"People call the material carried down by streams and rivers "sediment" (sĕd'ĭ-mĕnt). You may be interested to know where they get the word. It is from the Latin word which means "to sit." You know how sediment sits at the bottom of whatever contains it. If you take a cupful of muddy river water after a severe rain, you will soon see the sediment fall and "sit" on the bottom of the cup. You have surely noticed that after a heavy rain the color of streams and rivers changes. This is due to sediment in them; it has not yet had time to sink to the bottom of the stream.

The Business of a Little Stream

"You may think I am taking life easily nowadays, but you are mistaken. I am still hard at work in my quiet way. I am still wearing away the rocks. I am still carrying down sediment to the sea. I lay the sand on the bottom of the ocean, one layer carefully spread on top of another. The weight of the top layers is so heavy on the sand below that it is pressed into rock again.

"In the sediment I am carrying down a certain amount of mud, which I lay down in great beds on the sandstone rock. Where do I get the mud? I make it from the sand. It is merely sand ground fine.

"I have told you that I am still working. As proof of my great patience I may say that I have the ambition to wear away the whole of this mountain on which you are sitting, and to spread the material at the bottom of the sea. Although I have this continual hard work to do, I am very happy playing in the sunshine.

"Adventures? Yes, I have had more than my share perhaps. I once wandered in the world's first sea. It was a queer place. The water contained almost no salt and there was no life of any kind there. You must remember that I made my first visit to the earth millions of years before life had appeared. I watered the giant plants that were turned into coal. Great reptiles that have vanished from the earth bathed in my cool waters. Then the earth's long winter came. For centuries I was locked up in a great sheet of ice, which you call a glacier (glā'shẽr).

The Little Stream's Farewell

"Ah, my friends! Few can equal me in experience. I have bathed the warm banks of the Ganges in far-away India, and I have fallen as snow in the frigid north. I have explored every cell of the most delicate flowers, bathed every organ of the human body, and made my way into regions far below the surface of the earth.

"It seems only yesterday that I carved out the Grand Canyon. You will find my signature on the highest mountain peaks and in the lowest valleys. I am forever working, working, working. I destroy only to build anew. I am the little stream. I am eternal."

Millions of raindrops come dancing down upon the rippling stream and suddenly its clear speech turns to babble.

Reading Unit No. 9

HOW PLANTS AND ANIMALS MAKE ROCK

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is chalk? 1–51
What animal-made rock was used to build the pyramids? 1–51
What are Foraminifera? 1–51
What are diatoms? 1–51
What is granite? 1–52
How is marble formed? 1–52
What is plaster of Paris? 1–54

Things to Think About

What rock is chiefly the remains of skeletons of microscopic sea life?
What important building stones were formed by the exertion of pressure on the earth's crust?
What eventually happens to all the earth's rock?
What is the source of the minerals in tiny plants and animals of the sea?

Picture Hunt

How do animals form rocks? 1–52
How are natural bridges formed? 1–53
How does nature carve rock? 1–54

Related Material

Who advanced certain important theories concerning rocks? 13–430-31
How is rock carved? 12–95, 106
How was stone used for tools and weapons? 5–24, 11–2-3
How did the Mayans, Egyptians, and Romans use stone? 7–90, 11–409, 12–94, 102, 104
How is marble prepared for use? 9–381
Where did the Romans get marble? 12–111
Where is marble found in the United States? 9–380
How is limestone used in the manufacture of iron? 9–402

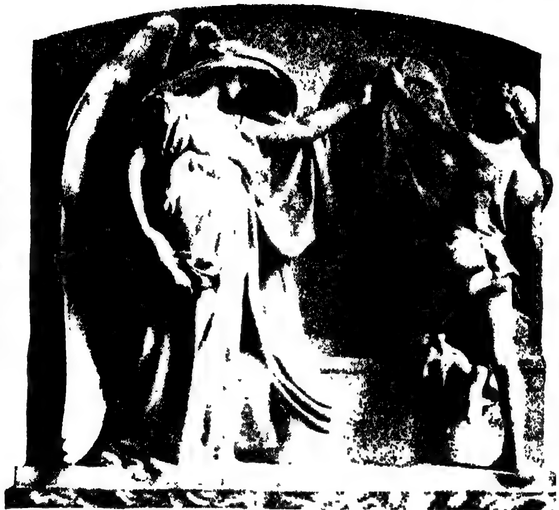
Practical Applications

How is stone used in buildings? 9–375, 379
How are statues carved in the sides of mountains? 11–361, 364
What materials are used in stone sculpture? 11–19

Summary Statement

The skeletons of tiny sea plants and animals, accumulated during millions of years, make present-day limestone.

Much of the limestone of the world is formed from the shells of tiny creatures that live in the sea. Great heat and pressure will turn the limestone into marble, the hardest and clearest of which becomes the favorite material of sculptors.



This famous marble group is the work of Daniel Chester French. It represents the angel of death appearing to the sculptor. With fateful touch she stays his hand, and his great work must remain unfinished.

Photo by Metropolitan Museum of Art

HOW PLANTS *and* ANIMALS MAKE ROCK

Tiny Creatures That Furnished the Stone for the Pyramids and the Marble for Many a Palace

DID you know that every time you write on the blackboard you leave millions of tiny seashells there? By this time you have learned so many amazing facts about the origin of the commonest things around you that you ought not to be surprised to find that chalk is made out of the shells of tiny animals. These little fellows lived and died in the sea millions of years before the dawn of man. But countless millions of them still live in the sea to-day.

You would not be very likely to call them animals, for they have no heads or legs; they are just little specks of jelly living in shells. But although they are very small, they have quite a long name: they are called Foraminifera (fŏ-răm′ĭ-nĭf′ēr-ȧ). Under the microscope they are beautiful to look at. They live in countless swarms near the surface of the water, and when they die, their tiny shells fall to the bottom of the ocean to make beds of "ooze." When the ooze has suffered the heavy pressure of the sediment deposited above it, it is transformed into what we call chalk. Under still greater pressure it is squeezed still more and then it turns into limestone. So the tiny creatures have had a good share in the world's work. The pyramids of Egypt were mainly built of limestone formed of Foraminifera so large that they can be clearly seen with the naked eye.

In the sea are also countless millions of tiny plants called diatoms (dī′ȧ-tŏm). They are so small that we cannot see them floating about. Perhaps you would not even call them plants, for they have no roots or stems or leaves; they are just like little specks of jelly. All the same, they are alive and they belong to the vegetable kingdom. Each of the tiny things has a very hard, flinty skeleton which it has made for itself out of the minerals in the water. When they die their skeletons fall to the bottom of the sea and after long ages are pressed together into soft, porous rock. Much of the limestone in the world was made in the ocean from little plants and animals like these; and every so often we find hidden in it the fossils (fŏs′ĭl), or skeletons, of fishes and other creatures that were tucked away in it when it was made.

Nature has employed many curious ways

of making rock. When the surface of the earth first cooled, the layer of rock that hardened around it was probably a form of granite, the artistocrat of rocks.

But it is certain that none of the granite that we find to-day was a part of the earth's first crust. All the rock we see has probably been made over and over many times, for Mother Nature is thrifty and nothing ever goes to waste. Our granite to-day was hardened long after the earth's crust was first formed and long after sediments had been laid down in the ocean.

You will remember how, as soon as the first water began to flow on the surface of the earth, it started to wear down the high places. The sand it ate away from them was spread on the floor of the early oceans, layer upon layer, thousands of feet deep, and eventually was turned to rock again to form other high places or mountains.

Many of the lower layers of this kind of rock had millions of tons of rock formed on top of them. The pressure of such a weight may raise the temperature of the lowest layers far above the melting point. Then a very interesting thing may happen. Under the enormous heat and pressure the limestone may turn into the most beautiful rock in the world. It may change to nothing less than gleaming marble!

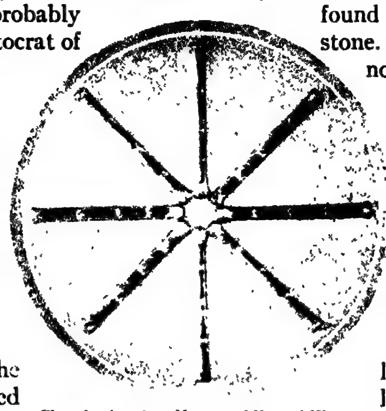


Photo by American Museum of Natural History

This is one of the tiny plants we call diatoms. Great layers of material have been formed as the plants died and their microscopical shells were mixed with other sediment and piled up beneath the waters. This is not so surprising when we learn that in one month one of these creatures can have as many as a million offspring!

There is plenty of evidence to prove this. A layer of marble followed to the end is often found to blend into a layer of limestone. In such a case, the heat was not intense enough at the end of the layer of limestone to turn it to marble. What was farthest away had to remain plain limestone.

But the geologist likes all the evidence he can get. In his laboratory he proceeds to heat and cool limestone under great pressure, just as we believe it was heated and cooled long ago deep down in the earth. The limestone in the laboratory turns to marble, just as it did in the earth. Then the geologist makes still another test. He puts a piece of limestone in acid; it bubbles and gives off a gas. Then he puts a piece of marble in the acid, and it gives off the same gas. So we know they are cousins.

What a tale it is—of torturing heat, of grinding, crunching, splintering rock, of writhing and twisting and upheaval! And the result of all the commotion is the strong and stately granite out of which we put up buildings made to last for centuries, and the exquisite marble out of which we cut our finest works of art. If it were not for all the heat and commotion, we should have nothing but sandstone and limestone—with a handful of little shells thrown in here and there.

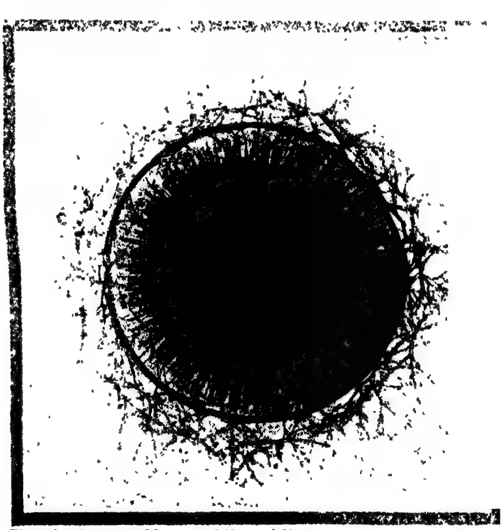


Photo by American Museum of Natural History

Radiolaria are tiny one-celled animals that build themselves flinty skeletons. When they die, these skeletons fall down to the bottom of the sea and, mixed with other materials, form great beds of a deposit called Radiolarian ooze. There are many kinds of these tiny animals; one kind is shown above.

This is the Natural Bridge, in Virginia. Bridges like this are usually formed in limestone, a rock easily worn away by water. A stream may once have flowed over the edge of the bridge in a waterfall. Then, perhaps, the stream found a crack, or "joint," in the rock a little way back from the edge of the fall. Bit by bit it began to enlarge the crack and eat under the bridge. Finally it formed another waterfall behind the first one. Then the falls worked back, tearing down the rocks over which they fell and leaving the bridge far in front of them. But this is only one way in which these bridges may have been formed.

But there are other and humbler rocks that can also tell a tale worth listening to. For instance, there is sober slate—red, purple, green, gray, or blue—which may, by chance, have mica in it and so shine with a soft luster. The tiniest particles of sand and clay went into its making, all laid down smoothly by the busy streams in layers on the floor of the ocean. As layer upon layer piled up, those at the bottom were pressed into thin layers of shale. But after ages of heavy pressure, they finally turned into slate, taking their differing colors from the various compounds of iron in them.

What Is Plaster of Paris?

There is a snowy substance, much like marble, which we know as alabaster (ăl′ȧ-bȧs′tẽr). It is also known as gypsum (jĭp′-sŭm), a substance from which the familiar plaster of Paris is made. And gypsum is a deposit of a simple material called sulphate (sŭl′fāt) of lime. It is found in inland lakes and in large quantities in the Dead Sea, and sometimes as thick beds of rock.

One of the humblest of all the rocks is the kind we call conglomerate (kŏn-glŏm′ẽr-āt)—or "puddingstone." *It is a kind of rock hash,* made of any sort of gravel and pebbles cemented together by a paste or clay or a natural mortar of sand and lime. You may see it everywhere. It is Nature's way of using odds and ends.

Our Ever-changing Earth

There are many other kinds of rock. Some were formed by heating, some by the hardening of sediment, some by plants and animals, and others by chemical action. But all of them are made in some way from the original rocks formed when the earth was young. To-day, to-morrow, and forever the process goes on. While you read these words, millions of tiny animals are falling to the bottom of the sea; their shells will one day form a layer of limestone. Tons of sand were spread to-day upon the ocean's floor; one day they will become part of another layer of rock. Deep down in the earth an unborn mountain may have risen an inch or so. Yonder hill has been worn away about a hair's breadth. Behind the veil of time, mountains rise and fall and ocean beds turn to green and fertile valleys. And the old earth spins on.

This is the Old Weather Prophet stone. Crowned with fir trees, it stands near Hopewell, Albert County, New Brunswick.

Nature is an original sculptor, and turns out many interesting carvings. This particular monument was made by her greatest of workmen, the sea.

Photo by Canadian Pacific Ry

Reading Unit No. 10

THE WORK OF THE BUSY CORAL

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What kind of island has no stone? 1-56
What tiny plant builds islands? 1-56
What very tiny animal builds islands? 1-56
Where do corals live? 1-56
What is an atoll? 1-57
Where is coral absent? 1-57
Which is the largest coral-constructed area on the earth's surface? 1-57
How far down does coral begin to grow? 1-56

Things to Think About

What difference would there be in the earth to-day if there were no coral?
How do certain plants help coral to build islands?
How long a time is required for the formation of a coral island?
Why are corals called animals?
How does coral help us know the history of the surface of the earth?

Picture Hunt

Of what use are the tentacles in certain corals? 1-56
Describe the different coral shapes, 1-57, 3-101

Related Material

How the coral polyp makes limestone, 3-97-99
How have corals affected the geography of the earth? 3-98-100
What does the sea do to corals? 3-100
The atolls, 5-520, 526, 529
How does the largest clam found on the Great Barrier reef use color to protect itself? 3-153
The different kinds of coral, 3-100
Which coral islands are the farthest north from the equator? 3-99
What other living things help corals build islands? 3-99-100

Practical Applications

What coral is used to make necklaces? 3-102
How do corals give us new rock? 3-99

Summary Statement

Tiny sea animals called corals, with the aid of minute plants called nullipores, form limestone reefs by leaving their chalky skeletons, one upon another, on top of undersea rocks.

Photo by American Museum of Natural History

These flowerlike members of a coral colony will add little to the hard material of the reef when they die, for their parts are mostly soft. But their brilliant tentacles add much to the beauty of coral pools.

The WORK *of the* BUSY CORAL

Little Mites That Can Make a Necklace or Build Up the State of Florida

OUT in the middle of the ocean there are certain islands where you cannot find a bit of stone. They are made by tiny animals and by algae (ăl′jē), a kind of tiny plant. The animals are the famous little coral polyps, and the algae are called "nullipores" (nŭl′ĭ-pōr).

The coral polyp (pŏl′ĭp) is very small, and looks like a bit of jelly, but inside its transparent body there is a hard, chalky skeleton. It lives in tropical seas, forming vast colonies in the warm water near the surface. Sun and air mean death to its frail body, and yet it can hardly live more than 250 feet beneath the surface of the water. Its world is as wide as the tropical ocean, but very shallow. The tiny blob of jelly is a living creature, with a mouth, a stomach, and a fringe of arms which are called tentacles (tĕn′tá-k'l).

Billions upon billions of these creatures live in the warm seas. When they die, their little skeletons may join to build up a reef or island in the ocean.

But they could hardly build a reef or island that would stand without the help of the nullipores. These plants secrete lime, making a much firmer deposit of it than the corals do. The nullipores are found in great numbers in the regions of breaking waves; and probably no coral growth could stand against the beating of the surf without the added strength that comes from the covering

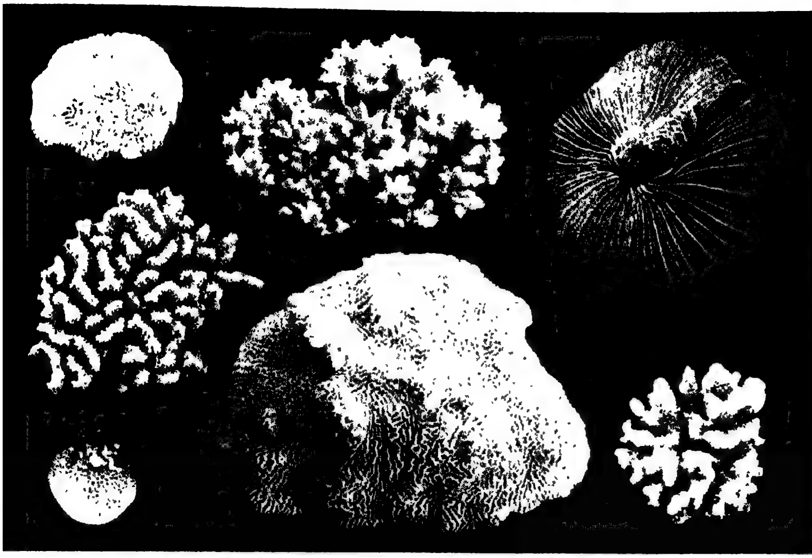


Photo [illegible] Museum of Natural History

Here are some of the beautiful corals which help to build the coral reefs of to-day. Since these animals can live only in the warm shallow seas, their fossil ancestors are very useful to geologists in finding out what past ages were like. When, for instance, coral remains are found in ancient limestone in the northern part of the United States, then we may be sure that those regions once had a milder climate than they have to-day, and were covered by a shallow sea. Otherwise no corals could have grown there.

of lime which the nullipores deposit on the coral lime itself.

The proportion of nullipores in a reef will vary greatly. In the Indian Ocean they may form only a veneer around the coral; in the Atlantic, as at the Cape Verde Islands, they may do the whole work of building reefs, without any help from corals. But how is it that great coral reefs and islands can be built by these tiny forms of life?

In the tropical seas there are numerous shoals. Some of these will be just a little too deep for coral growth. But very slowly these shoals, far out from the land, are being built up by the bones of animals that sink down on them, by volcanic dust, and by other deposits. When a shoal gets up to about 250 feet below the surface, in some place where the water is very clear the reef corals may start growing. The first of these die and leave their skeletons as a foundation for the next ones to build on. All the while a mount of coral is thus growing on the shoal, and in a few thousand years it may get to the surface, peeping out as a coral island, where living things may find a home.

There are many such formations in the southern seas. In the Pacific Ocean a good many of them have been shaped into what we call "atolls" (ă-tŏl′). An atoll is a ring-shaped reef encircling a lagoon or lake. In the days of sailing ships, these reefs served as harbors during storms. Coral is not found on the west coast of America or of Africa, but it is very plentiful in the Central Pacific, the Red Sea, and in the Indies.

One cannot imagine what countless billions of coral polyps went to build the Great Barrier Reef which lies off the east coast of Australia. It is 1,250 miles long and at places ninety miles wide; and it covers as much area as do certain powerful nations. But much nearer home, our own state of Florida was built largely by the patient labor of corals.

Reading Unit
No. 11

WINTER FOR THOUSANDS OF YEARS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How may an avalanche begin? 1-60
What makes a glacier flow like a river? 1-59-60
How did round boulders get their shape? 1-60
What did the glacier do to the rivers of Central North America? 1-60
When were many of the lakes of America formed? 1-61
Where does the Ice Age still exist to-day? 1-61

Things to Think About

What do scientists believe was the cause of the Ice Age?
How are icebergs related to glaciers?
If another Ice Age occurred, where would living things go to survive?
Why would an Ice Age to-day be more destructive than in the past?

Picture Hunt

What part of North America was covered by ice? 1-61
How is a pothole formed? 1-62
What may a glacier carry along with it? 1-63

Related Material

What is the effect of the glacier upon Alaska? 1-197
What were some of the forms of life during the glacial epoch? 3-64
What is glacial soil? 1-97
How did the Ice Age affect the eastern shore of the Baltic? 6-460
How did the Ice Age change the surface of Scandinavia? 6-371
Where are the highest glaciers to be found? 13-517

Practical Applications

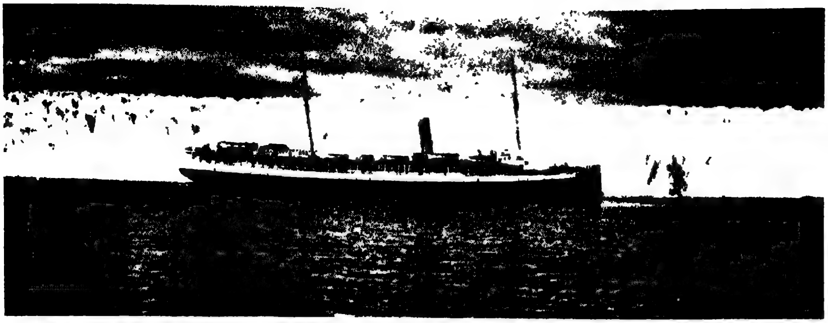
How is shipping protected against floating portions of glaciers? 1-64
How do we trace the original source of non-native rock and soil? 1-59-63

Leisure-time Activities

PROJECT NO. 1: Find out if there is a glacial drift in your neighborhood, 1-63.
PROJECT NO. 2: Find out if there are any glacial scratches on rocks in your neighborhood, 1-63.

Summary Statement

Thousands of years ago, Northern Europe and North America were covered by a huge moving ice sheet which made great changes in the surface of the earth covered by the ice.



Pacific Railway

In certain parts of the world the Ice Age is still going on. Here is a great Alaskan glacier that gives birth to icebergs at the point where its white mass reaches the sea. There vast chunks of it break away with a thunderous roar, and float away on the ocean current to perish in warmer waters.

WINTER *for* THOUSANDS *of* YEARS

When the Ice Buried the Mountains and Flowed in Vast Streams over the Land

SUPPOSE a great field of ice should come creeping down upon us from the north until hills and valleys, forests, farms, and busy towns were as completely buried as if sunk beneath a frozen sea. If we wanted to keep alive, we should have to flee to the Tropics—and even there we should not find it very warm. Yet this is just what happened once upon a time—and fairly recently in the earth's history, though long enough before our own day.

For the people of that frigid era life must have been a bitter struggle. To be sure, the ice came down on them very slowly; but all over our part of the earth the climate grew so cold that they must have had a hard time finding food and keeping warm. Certain kinds of animals died out altogether. Of course the earth of that day was a vast wilderness, without farms or cities, so the deadly ice could not destroy so much as it could to-day. But it was bad enough; it covered all the northern part of North America and of Europe.

We call that long winter the Ice Age, or Glacial (glā'shăl) Age. Its length we do not know, nor its cause either, but we do know it must have lasted thousands of years. When in 1840 Louis Agassiz (lōō'ĭ ăg'ȧ-sē), a famous Swiss scientist, said that there had been an Age of Ice, many people laughed at the idea. To-day we are sure that he was right, for we can see where the ice left its signature in many ways. And although it is thousands of years since the Age of Ice, its story has come down to us more clearly, written on the face of the earth, than the story of many a tribe and nation that lived far more recently.

The gigantic sheets of ice that crept over the earth during the Ice Age are called "glaciers" (glā'shẽr). At the start they were made of snow. But snow will turn to ice when under heavy pressure. As the deep mountain valleys filled with snow, the weight of the drifts above and behind pressed with such enormous force on the snow below that the lower layers were changed into huge masses of ice—sometimes as deep as a mountain is high.

Now we think of ice as very hard—almost like stone. But in reality it yields to pressure fairly readily, as you may notice if you ever leave a heavy pan or pail sitting on a cake of ice—even though the ice and the pail are both far below the freezing point. As a re-

sult, ice will seem to flow when it is put under very heavy pressure, though it moves very, very slowly. It is in glaciers that ice may be seen "flowing" on the largest scale, for the lower part of the glacier will flow forward under the enormous pressure of the ice and snow on top. This is going on all the while in the glaciers of Switzerland and Greenland. If it were not for this "flowing," the ice on mountain tops where it is never warm enough to melt would pile up higher and higher until it would break off in vast masses by its own weight and come crashing down into the valleys in death-dealing avalanches.

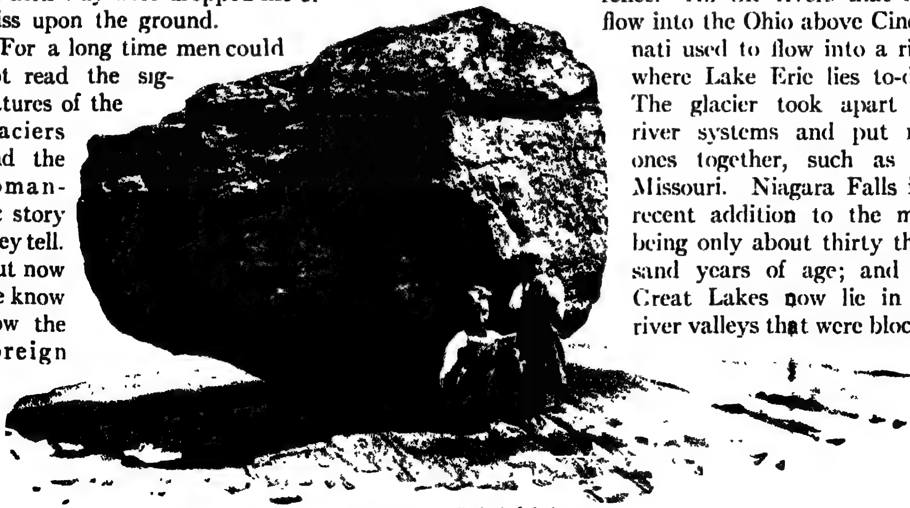
The Glacier's Signature

As the glaciers of the Ice Age crept down the mountain sides and flowed over the valleys, they gathered up stones and frozen soil to carry along with them. The stones carried at the bottom of the glacier were rounded and polished as the mass of ice above rubbed them over the earth and stone beneath; and in the stone they left scratches that we can often see to-day, all pointing the way the glacier was going. All of us who live as far north as New York have seen these signatures of the glacier though we may not have known what they were. Finally the long cold period ended. The masses of ice slowly melted; and the stones and soil they had gathered on their way were dropped hit or miss upon the ground.

For a long time men could not read the signatures of the glaciers and the romantic story they tell. But now we know how the foreign soil and the smooth round stones that we find in many places were brought there from very different homes. They certainly look like strangers; they are quite unlike the rest of the soil and the bed rock where we find them now; and they are so smooth and round that something must have been polishing them. Also the bed rock underneath them has been ground and scratched, showing that something very heavy has passed over it. Now if we are clever enough to follow the scratches mile after mile over hill and dale, we shall always come to a place where the original rock is the same as that in the smooth round stones we saw so far away. That is where the glacier picked them up.

Many of us have seen huge rounded stones lying in such perfect balance that we can rock them back and forth with our hands. These were rounded and left behind by the glacier long ago. Often we find them on the tops of mountains, where the mass of ice that carried them must have been five or six thousand feet deep.

None of us would know a map of North America as it looked before the Ice Age. Many of the rivers flowed in an opposite direction from their present course. The great Mississippi was pushed back and forth, and some of the smaller rivers that used to flow into the Mississippi turned around and joined the St. Lawrence. All the rivers that now flow into the Ohio above Cincinnati used to flow into a river where Lake Erie lies to-day. The glacier took apart old river systems and put new ones together, such as the Missouri. Niagara Falls is a recent addition to the map, being only about thirty thousand years of age; and the Great Lakes now lie in old river valleys that were blocked

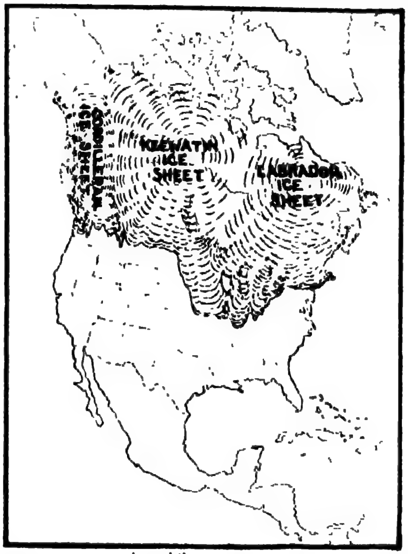


The great boulder these young people are leaning against so comfortably is a "rocking stone" in Bronx Park, New York. It was dropped there by a glacier, and now lies in such perfect balance that we can rock it to and fro with a push of the hand.

Photo by N. Y. Zoological Society

up by soil and rock which the glacier left. All over the region the masses of ice deepened canyons, shaved the crowns of mountains, and carried billions of tons of soil from place to place.

As a direct result of this uneven dumping of sand and rocks, thousands of lakes were born where none had been before. Some of them vanished with the ice, for they depended on the walls of the glacier to dam up the water. But many of them are still there, with walls made mostly of the rock and soil left by the ice. The famous Finger Lakes in New York State were made from rivers that the glacier dammed; and Lake Winnipeg is all that now remains of a great sheet of water, larger than our present Great Lakes put together, which once covered portions of Minnesota, North Dakota, and Manitoba, and which is now referred to as Lake Agassiz. For to that vast pond of the earlier days we have now fitly given the name of the great man who brought forth the theory of the Ice Age.



This map shows how the great ice sheets spread from their three main centers. As you can see, the ice came down far enough to cover all of New York State, northern Pennsylvania, most of Ohio, Indiana, and Illinois. West of the Mississippi the ice covered the northern half of Missouri, eastern Nebraska, the eastern half of South Dakota, and almost all of North Dakota. Farther to the west the ice extended only a little distance south of the Canadian border. If you live within this territory, watch for landmarks left behind by the glaciers.

There are many guesses as to why the Ice Age came about, but all of them are very far from certain.

What Caused the Ice Age?

Some of the astronomers think it may have come from a change in the earth's orbit around the sun. Such changes do occur, they say, though they are millions of years apart. And it is true that the earth has passed through various ice ages; we can find traces of them, though many of their marks have been wiped out by the vast changes since their time. Other scientists say that a change in the atmosphere or a great rise of the land in certain regions may have caused the ice to form in vast masses. But no one really knows. It is possible enough that the Ice Age had a number of causes, all working together.

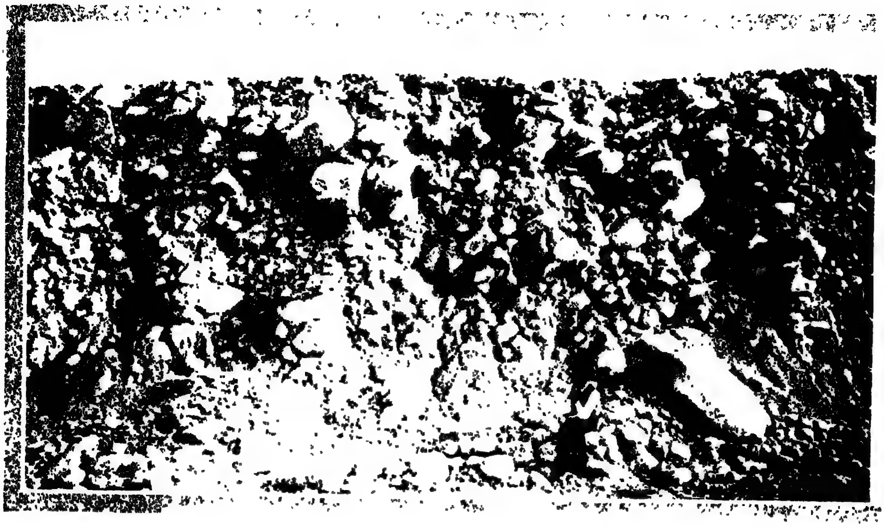
There is a trace of the Ice Age in the world to-day, though we do not usually think of it in that way. The North and South Poles are covered with ice, and in Greenland there is hardly anything but ice to be seen. In the Alps there are nearly two thousand small glaciers, from a mile to over ten miles long and some miles wide. It was in the Alps that Agassiz made the great discoveries that led him on to form his theory of the Ice Age. He saw that although a glacier flows very slowly it gets along fast enough to let us see that it has uprooted trees and piled up more and more rock and soil in front of it. He found a mountain hut changing its position because it was riding along with the ice, and by it he measured the speed of the glacier as it crept along. From these things he divined that there had been great glaciers of old, and in this way he explained a great deal about the face of Northern Europe and America to-day.

The three great "central stations" from which the glaciers seem to have started down over our continent are called the "Cordilleran (kôr′dĭl-yä′rän) Center," the "Keewatin (kē wä′tĭn) Center," and the "Labrador Center." Our Ice Age map shows the way the ice traveled from each of these centers, and how far it came down the sides of the world. It came well down into the United States, and into Germany and Russia, for our own little mountain glaciers to-day are not to be compared with it for size. Though it did not cover the globe, it must have made

The ice sheets did strange things to the lands over which they passed. In some places they scraped off all the loose soil, leaving the hard rock beneath, scratched and bare as you see it above. Then what the glaciers took up in one place, they dumped down in another. Many a low, irregular series of hills was formed in this way out of the material the cumbersome "river of ice" had picked up in its travels.

Photo by N. Y. Botanical Society

"Potholes" like these are sometimes formed in the rock beneath a glacier when a surface stream cuts a well-like channel in the ice and then begins to whirl around. It bores a hole much as a corkscrew would.



This bank of "glacial till" or "glacial drift" shows you the sort of material a glacier carries about with it. When a stream flows slowly, the bits of material it carries are very small; but of course the faster it flows, the larger are the particles it can carry. Now a glacier is an entirely different matter. It can pick up anything that comes its way - from a tiny speck of dust to a great boulder. So when it dumps its load, you will find the odd assortment of rocks which you see in the picture above.

vast changes in the climate everywhere.

A great many people confuse a glacier with an avalanche (ă'vȧ-lănch), though the two are not at all alike. An avalanche is simply a great mass of snow or ice that piles up on a mountain side until it breaks away of its own weight and rushes down with terrific force into the valley leaving death and destruction in its wake. Often an avalanche is a piece of a glacier that has broken away. If it is on the seacoast, it then becomes an iceberg.

These tremendous boulders traveled some distance over Europe before the glacier that carried them finally left them piled up as you see them here.

Greenland is the mother of icebergs. They are always being born around her coasts, especially in Baffin Bay and in the Davis Straits. The manner of their birth is always the same. A great glacier keeps pushing its nose out into the sea, where its ice floats in the water. The tides and the heaving waves put a strain on the ice at the water's edge. In due time it cracks, and the floating mass breaks away with a terrific noise like thunder. An iceberg is born. The glittering mountain will roll over and over as it breaks off into the sea, but finally

gets its balance and comes to rest. Then it stands up in its majesty and floats off down the ocean, borne along by winds and currents to its death in southern latitudes. The greater part of it lies under water, and only a rather small fraction—perhaps an eighth or ninth—will show above the waves. So an iceberg standing 300 feet above the water must go down some 2,000 feet below the surface.

Icebergs are made of fresh water, since they come from inland glaciers which are so huge that they keep pushing into the sea. For glaciers are always on the move. One of the largest and best-known is the Muir Glacier of Alaska. It stands at the head of a large inland basin and covers an area of 350 square miles. It ends in an ice cliff 250 feet high, from which great icebergs break off.

Icebergs drift into the ocean, where certain of them—especially those from Greenland—are a great danger to shipping. As soon as they are seen at sea, they are reported by wireless, for the warning of other vessels. There are several ways to detect distant icebergs. One of the most ingenious is based on a discovery made a hundred years ago. If two different kinds of metal are joined together and the point where they meet is cooled, an electric current will be set up. Now an iceberg cools the water all around it for a good way. So as soon as our sensitive device gets into water of a lower temperature, an electric current is started which switches on another current that lights a red lamp and rings a shrill bell. Doubtless radar will be one of our best iceberg detectors.

On Sunday night, April 14, 1912, the great liner "Titanic," then the largest steamship afloat, ran into a great iceberg on her first, or "maiden," voyage from England to America. At first it was thought that little damage had been done, but later the distress signal, called the "S.O.S.," was sent out. Very soon another liner replied that she was hastening to the rescue, and in all eleven ships set off to give help. It seemed that the first one would arrive in time to take off all the passengers. Even when the order came for all persons to put on life belts and report on deck, the danger was not realized; the passengers believed they would soon be back in their cabins. But the damage was very serious. The iceberg had ripped off great steel plates from the vessel's side and she was rapidly filling with water. When the women and children were put into the lifeboats, everyone knew it was impossible to take all the passengers; many had to remain on the ill-fated vessel. She went down in the middle of the night. The rescuing liner arrived after the "Titanic" had sunk and picked up the people in the lifeboats or in the water. There had been over 2,300 on board, but only some 700 were saved.

And where do icebergs go? They melt in the sea or run aground on some shore, such as the Newfoundland Banks. Those great shallows are six hundred miles long and two hundred miles wide. The place is a graveyard for icebergs, which add, in their turn, to the deposit, for they often carry stones and soil with them. But sometimes they float as far as two thousand miles before they melt and drop their burden in warmer waters.

This explorer is taking soundings in the South Polar regions to find the sea's depth and bring up samples of material from the ocean floor. He can also take the ocean's temperature at different depths.

Soundings may tell the scientist many things—whether, for instance, he is in a continental, or land, area or whether he is standing on the frozen waters of a great ocean basin, perhaps one of great depth.

Photo by Herbert G. Ponting from the "Great White South."

Reading Unit No. 12

WHAT THE OCEAN HIDES

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the average depth of the ocean? 1–66

What effect have the different seasons upon the ocean deep? 1–66

How great is the water pressure one mile beneath the surface of the ocean? 1–66-67

What is a diving bell? 1–67

How far can man descend into the ocean? 1–67

What do we find on the ocean floor? 1–67

What rivers flow through the ocean? 1–67

Things to Think About

Why do scientists believe that the hardest rock is under the deepest water?

Why can fish live at great depths in the ocean without being crushed?

Explain how it is that, although the oceans average two and a half miles in depth, we may nevertheless say: "The oceans are like a film of water on a football."

Picture Hunt

How can deep-water fish see in the total darkness of the ocean's depths? 1–67

How much of the earth's surface is covered by water? 1–66

Related Material

What sea animals give us gems? 3–162

What depths have been reached in the ocean? 1–367

How are sponges gathered? 3–87

How may a diver increase the time during which he can hold his breath? 2–341

What kinds of diving apparatus are in use to-day? 10–521-26

Where do we find volcanoes under the sea? 1–76

How are soundings of the ocean taken? 1–64

Why has the ocean been the highway of civilization? 10–163

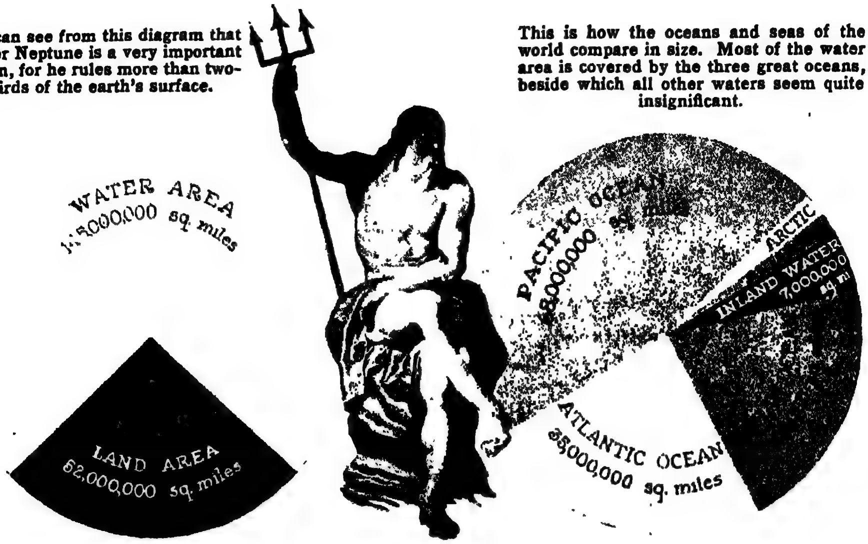
Leisure-time Activities

PROJECT NO. 1: Make a chart comparing the water and land areas of the earth, 1–66.

PROJECT NO. 2: Make a chart showing the relative sizes of the earth's important bodies of water, 1–66.

Summary Statement

The oceans and other bodies of water cover almost three-fourths of the earth's surface to an average depth of two and a half miles.



You can see from this diagram that Father Neptune is a very important person, for he rules more than two-thirds of the earth's surface.

This is how the oceans and seas of the world compare in size. Most of the water area is covered by the three great oceans, beside which all other waters seem quite insignificant.

WHAT *the* OCEAN HIDES

Some of the Strange Things We Should Find if We Could Get Near the Bottom of the Sea

IMAGINE the surprise of an African native who has always lived inland when he suddenly sees the ocean for the first time. Some of these simple souls were very much alarmed when they started out for Europe at the time of World War I; they did not like the idea of going out of sight of land, and begged to be taken back. The captain assured them that they would reach land the following day at a certain hour, and since it happened as he had prophesied, they grew confident that he knew what he was about. But the experience was a trying one.

Even the most traveled of us find it difficult to realize the size of the sea. It covers nearly three-quarters of the earth. It varies greatly in depth, but on the average is about 2½ miles to the bottom. To us this seems quite deep enough, but in comparison with the vast size of the globe the sea is only a very thin layer. If we dipped a football in water and took it out again the film of water that would cling to it would be about like the film of ocean on the surface of the earth. We have to compare eight thousand miles of earth with only two miles of water the depth we should have if the ocean were spread evenly over the whole of the globe.

Three hundred years ago a famous navigator thought he had found the deepest part of the ocean when he took a sounding at two hundred fathoms, or twelve hundred feet. But now we have found a depth of five miles in the Atlantic Ocean and more than six miles in the Pacific, near the Philippine Islands. For the Pacific is the deepest of all oceans; its average is 2¾ miles.

From the surface of the water we cannot see the floor of the sea because the light cannot reach so far. Although no one has ever been down to the bottom, we are sure that it is absolutely dark there. Below a depth of six hundred feet, the seasons have no effect. There is neither spring nor autumn; all is winter. This is true even in the warm Tropics; the water at the bottom of the ocean is icy cold. In those depths the surface waves have no effect. Everything is still, except for the motion due to currents

that are always present; but the motion is a slow one. A terrific pressure from the water up above rests upon the lowest depths. One mile down, the weight is about a ton to the square inch, and at six miles it is six tons.

The atmosphere presses upon everything with a weight of fifteen pounds to the square inch, but it does no harm to even a fragile object that has air within it, for the air within is pressing outward with an equal force. For the same reason some fishes can live in deep water because their bodies hold water of the same tremendous pressure; but a man will feel the weight. He has never been able to go down more than 1,426 feet, even in a diving bell—a hollow ball or bell-shaped compartment made of cast iron or steel.

A Peep at the Floor of the Sea

The floor of the sea in shallow water is chiefly made of sand and mud which have been brought down by rivers. In deeper water we find "ooze," which is formed of the shells cast off by plants and animals too tiny to be seen with the naked eye. In very deep parts of the ocean we do not find much ooze, but chiefly a red clay. Below all this is the solid rock which forms the crust of the earth; and many scientists believe that in deep water this is the oldest of all rock, on which very little sediment has been built up. It would be part of the earth's first crust.

You may have heard of the voyage of the "Challenger" (1873–1876), a scientific trip which did much to find out what the floor of the ocean was like. In a single haul from the bottom of the ocean there came up sometimes as many as a thousand sharks' teeth and sixty ear bones of whales, showing what an enormous number of such animals there must have been during the earth's history.

Man has not seen very much of the ocean's bottom. We know of great canyons in it—five times deeper than the Grand Canyon of the Colorado. One of them, off the coast of Japan, is over twelve hundred miles long and one hundred miles wide. Surely no natural feature on the land could compare with it for grandeur.

In many places within the reach of divers the floor of the sea looks like a garden filled with fairylike shrubs and flowers—fragile animals that make their homes there. Elsewhere there are hills, mountains, valleys, plains, and volcanoes. Here dwell the most fantastic creatures in the world. Shark-nosed demons, glowing like ghosts, haunt the darkness. Their shapes and their varieties are endless.

Of unusual interest is the fact that there are great rivers, or currents, in the sea. Their beds and banks are made of water that is of a different temperature from that in the streams. We all know of the great Gulf Stream. It is a genuine river of warmer water coming out of the Gulf of Mexico, flowing up the coast of North America, and then making its way across the Atlantic Ocean to warm the colder waters of Western Europe. It is about fifty miles wide and two hundred feet deep. Its rate of flow through the surrounding waters is a walking pace of about five miles an hour.

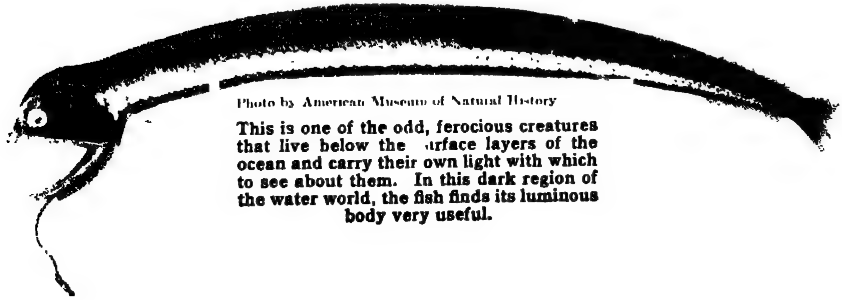


Photo by American Museum of Natural History

This is one of the odd, ferocious creatures that live below the surface layers of the ocean and carry their own light with which to see about them. In this dark region of the water world, the fish finds its luminous body very useful.

Reading Unit
No. 13

HOW THE SEA CARVES UP THE CONTINENTS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Where are the oceans unusually shallow? 1–69

What is the sea doing to Heligoland? 1–69

How high may waves reach? 1–69

How much English soil does the sea eat away each year? 1–70

What does the salt of the sea do to rocks? 1–70

Where is land rising out of the ocean? 1–70

Why does not Holland disappear under the sea? 1–70-72

What happens to land that the sea steals? 1–72

Things to Think About

How much larger would England be if the sea did not wear away her shores?

What would be the effect upon rocky shores if the sea did not contain salt?

How has the rise and fall of the earth's crust affected the geography of Europe?

If the waves remove one foot of shore line every year, how long will it take the sea to wear New England completely away?

Picture Hunt

How can the ocean form separate pieces of land? 1–69

How does the sea take advantage of the structure of rocks in carving them into queer shapes? 1–70-72

Related Material

How were the grottoes of Capri formed? 1–87, 6–476, 480

What does the ocean do with sediment? 1–49

How is the supply of ocean water maintained? 1–235, 239-41

What did the ocean do to the Zuider Zee? 6–353

How the streams wear away their beds, 1–47-48

The birthplace and the grave of a mountain, 1–22

Practical Applications

Why is there a sea wall along the shore at Galveston, Texas? 1–70, 72

How may we prevent the loss of life that results from changes in the surface of the earth? 1–69-72

Leisure-time Activities

PROJECT NO. 1: Look in your neighborhood for rocks which have been carved by bodies of water, 1–69-72.

HOW *the* SEA CARVES UP *the* CONTINENTS

The Hungry Waves Are Always Eating Away the Land in Some Places and Building It Up in Others

COME and watch the breakers rushing in upon the shore. See how they pound upon the rocks and eat away the sand. Now they are gathering up all their forces for the assault; now they come roaring in, grinding the pebbles, crushing the sea shells, shifting the sands, and pitching the bathers head over heels. All day long they keep up the attack, and the night will bring no rest. If a great storm comes, they may lift their foaming crests thirty or forty feet, and break upon the shore with merciless force. Along a few miles of coast they will be spending enough power to run all the mills of a big city.

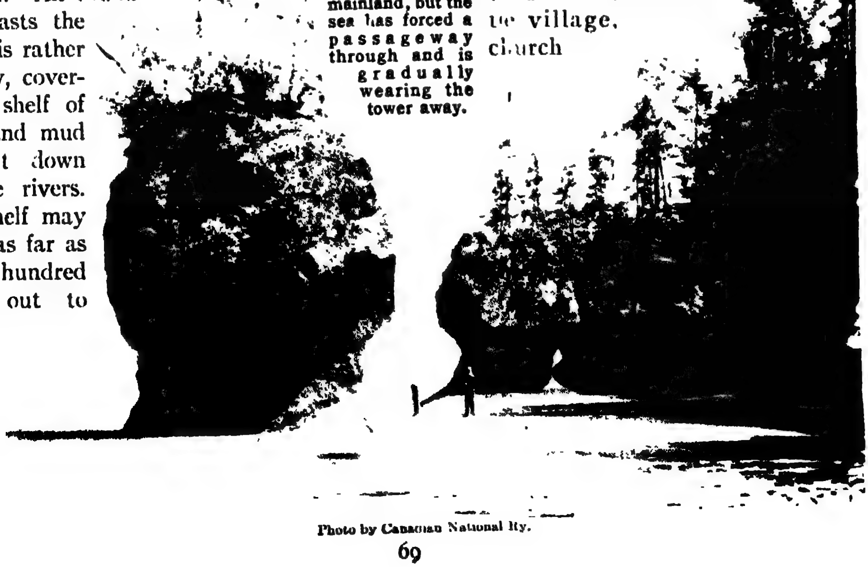
Such is the mighty rasp which, day after day, century after century, saws away at the fringes of the continents. It is hundreds of thousands of miles long, for the ocean covers nearly three-quarters of the globe and washes almost every country.

Although the floor of the sea has its mountains and valleys and volcanic mounds, in general it is fairly smooth. All round the coasts the water is rather shallow, covering a shelf of sand and mud brought down by the rivers. The shelf may reach as far as three hundred miles out to sea, though it is usually a good deal narrower. At any time a part of it may be lifted up out of the waters to make a new land.

Or the sea may alter its shore by the constant pounding of the waves, and offer us quite a different kind of beach from the one we knew only last summer. Instead of gently sloping sand, we may find a strand covered with stones, and quite steep. The waves may even have stolen away the beach entirely, and have ground the rocks to sand. This is what has happened year after year to Heligoland, an island in the North Sea that acts as sentinel to the Kiel Canal. In 800 A.D. it was 120 miles around, but now it has only three miles of shore left.

How the Sea Is Stealing the Land

Within the last few centuries whole villages along the southeastern coast of England have sunk into the ocean. Standing on the edge of a sea cliff near the mouth of the Thames is a church that some four hundred years ago was a mile inland. And off the same coast is a little village. church



This rounded hump of rock was once joined to the mainland, but the sea has forced a passageway through and is gradually wearing the tower away.

Photo by Canadian National Ry.

Photo by L. M. & S. Ry.

As the sea gnaws away at the continents, it carves out many strange and beautiful rock structures. The archway you see in the picture above has been chiseled out of rock on the English coast.

all, that is now far down below the waves—and with it goes a pretty legend of fairy bells that ring on Sabbath days.

Every year no less than fifteen hundred acres of England's soil are eaten up by the sea. Along the eastern coast the blows of the angry waves often shake the earth a mile back from the shore. During heavy storms the breakers pound the cliffs so hard that boulders weighing as much as three tons are pried loose and carried off by the heavy undertow. The next onrush of waves will seize them and hurl them against the cliffs; and so the grinding will go on.

One of the Sea's Deadliest Weapons

Salt is another of the sea's deadly weapons. The waves force themselves into the pores of the rock, where, under the chemical action of the air, the salt helps to eat the solid stone away.

But the ceaseless beating of the waves is not the only thing that shapes the seashore. The lifting and sinking of the earth's crust does its share. The land around the northern part of the Baltic Sea is rising at the rate of one inch every two and a half years, though Southern Denmark is sinking. Great Britain was once a part of the mainland of Europe, and the English Channel a dry valley Labrador and the Pacific coast of North America are rising, as well as parts of Japan, but other parts of Japan are sinking so fast that whole settlements have been buried beneath the sea. In some places there the land is being lowered as much as a foot every five years. But even though the continents have risen and fallen a few hundred feet, the present floor of the deep ocean has probably never been above the sea, nor have the continents ever formed the bottom of an ocean.

Sometimes great walls are built around a coast where the waves are especially threatening. Holland would be flooded if it were

Photo by Anderson, Rome

The waves take advantage of every chink and crack and every weaker layer of rock they find. Sometimes, when the rock is hard and unbroken, the waves as they cut back terraces at water level will develop steep sea cliffs. At other places they may find huge cracks in the rock, and by nibbling away the material along the cracks they will cut great towers of rock from the mainland. These tall "chimney" rocks are then like so many giants striding out to sea. Our picture shows what the waves are doing to the island of Capri.

not for her dikes. At Galveston, in Texas, a sea wall was put up after a disaster in 1900. The damage at that time came from a hurricane which raised great waves and flooded the city. Galveston is built on a very flat island and is nowhere more than ten feet above sea level. Its people were so well used to tropical storms that when the wind began to blow on a morning in September they felt no alarm. Even when at noon it had risen to a hurricane, they went on with their work as usual.

But by three in the afternoon the wind was so high that people began to take fright. Business places were closed, and men thought it wise to go and see that their families were safe. Soon the wind and waves made it impossible to get from place to place. By this time all the wooden buildings had fallen and many stronger ones had been damaged. Bridges were blown down; and since the bridges were all that joined the island with the mainland, all communication with the outer world was cut off.

The storm kept on into the night, sweeping gigantic waves up over the land; but by midnight the wind had spent its force. At first it was thought that only about a thousand people had been killed, but later it was found that nearly four thousand were dead. The disaster was so great that at first it seemed better to abandon the whole town. But finally a great sea wall was built instead.

The wind and waves may do a good deal of sudden damage, but their greatest destructive action takes place over long ages. We are not used to thinking in terms of geologic time, and for this reason it is hard for us to understand the great changes that are slowly but constantly going on around us. If the sea were to remove only one foot of land from the New England coast each year, the whole of New England would be gone in a little less than 750,000 years. This seems a very long time to us, but it is only a fleeting moment in geologic time.

Yet we must not think of the sea as a destroyer only, for much of the land it steals from one place it deposits at another. In this way, it builds up islands and enlarges continents. It is constantly making new lands while it tears down old ones.

Here is another of Nature's strange carvings. The sea will continue its work of destruction till some day this giant will tumble headlong into the water. Then its bones will be scattered far and wide as the sea tosses them about.

Photo by Canadian Pacific Ry

Reading Unit No. 14

THE FLUES OF THE FURNACE UNDERGROUND

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What did the ancient Greeks believe about volcanoes? 1-75
How did volcanoes get their name? 1-75
What does a volcano send into the air? 1-75
How may a volcano build a mountain? 1-75
How long does it take for a volcano to become a mountain? 1-75
How deep is a volcano? 1-75
What kind of rock do we get from volcanoes? 1-76
Where are most of the earth's volcanoes to be found? 1-76

Things to Think About

How have volcanoes changed the surface of the earth?
How have volcanoes affected people's lives?
Why are undersea volcanoes possible?
What is happening to the number of active volcanoes?

Picture Hunt

Describe the cone and crater of a volcano, 1-74
What happens inside a volcano? 1-75
How is a volcanic pipe formed? 1-75
Pele's hair, 1-10

Related Material

The geysers, 1-32-36, 7-406
The only volcano in the United States, 7-407
Other active volcanoes, 8-16, 460-A
If there were no volcanoes, what important United States possessions would not exist? 1-10, 5-521, 526, 528
Which great Roman city was destroyed by a volcanic eruption? 5-238, 257, 13-53
What plants grow in volcanic craters? 2-258
What mountains were formed by volcanic action? 1-22

Leisure-time Activities

PROJECT NO. 1: Make a clay model of a volcanic crater, 1-74.
PROJECT NO. 2: Make a colored cross-section diagram of an erupting volcano, 1-75.

Summary Statement

Volcanoes occur when some of the very hot materials below the earth's crust break through weak points in the crust.

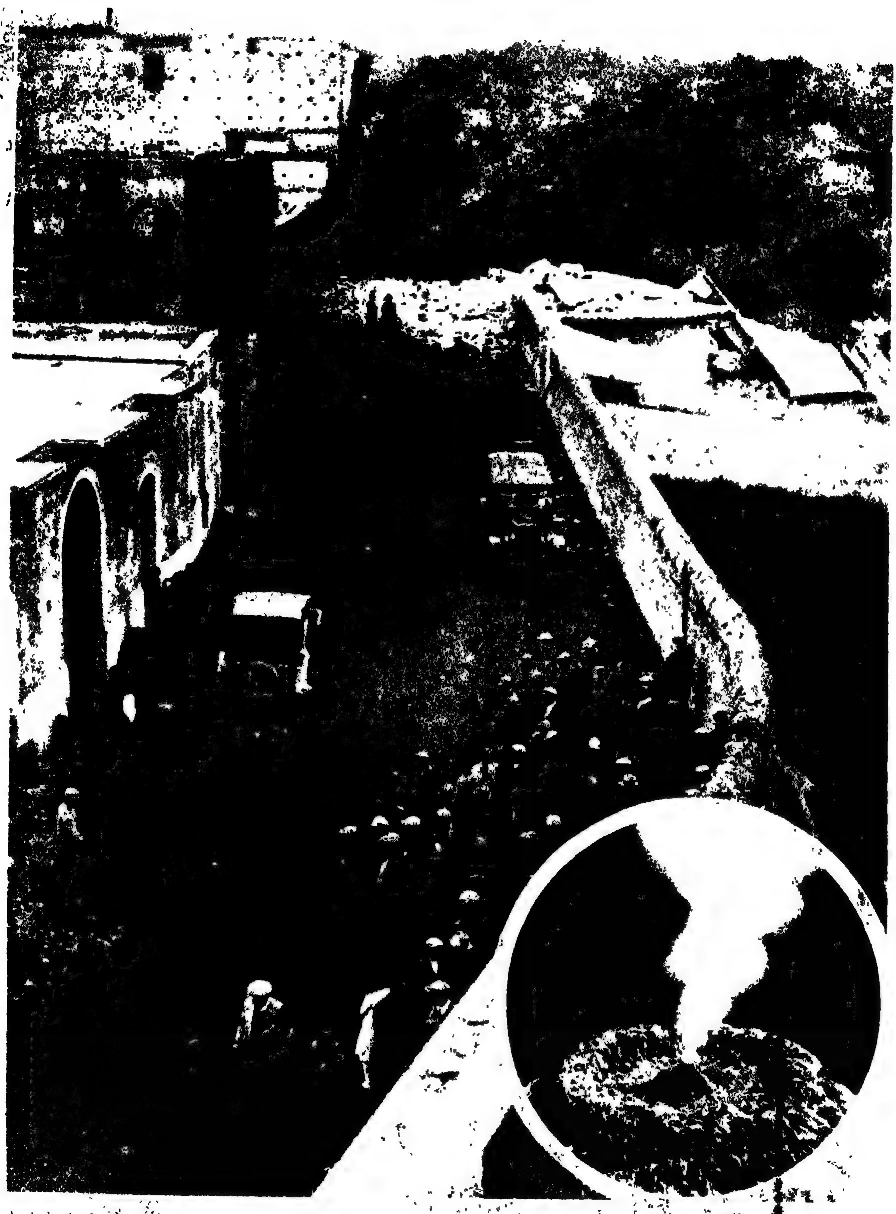


Photo by Instituto Nazionale, Rome

Vesuvius is rather a well-behaved volcano - as volcanoes go—but on several occasions it has behaved very badly. For years it slept peacefully and was overgrown with grass and trees. But in 79 A.D. a terrible explosion blew away a great part of its cone and buried Pompeii in a blanket of rock dust thirty feet deep. Since that time its eruptions have been periodic and sometimes very disastrous. Above, you see the results of an eruption which took place not long ago. In the circle is the crater of the volcano, showing the little cone the monster is busily building itself out of the material that it spews forth.

The FLUES *of the* FURNACE UNDERGROUND

What Will Happen if the Molten Metal inside the Earth Finds a Crack in the Crust?

VULCAN was not a happy god. For one thing, he was a cripple. There had been a famous quarrel when his father Jupiter had sent him hurtling out of heaven, in a fit of rage because the boy had sided with his mother Juno in one of the family squabbles. Vulcan had got a dislocated hip in the fall, and vowed he never would go back to Mount Olympus, where the greatest of the gods of Greece were said to have their home. Since he was the god of fire and had always had a mechanical turn of mind, he made a forge underneath Mount Etna and took a race of one-eyed giants called the Cyclopes (sī-klō'pēz) into partnership. There he made all sorts of useful articles out of metal, even to golden handmaidens to wait on him. It was he who forged Jupiter's dread thunderbolts, which the great god hurled about whenever there was a storm.

The men who worshiped him thought of Vulcan as a short, muscular person, with one leg longer than the other and a workman's cap upon his curly locks. He wore a long sleeveless jacket and carried a hammer. All blacksmiths and metal workers considered him their especial friend. The Greeks liked to have a reason for everything; so when the wise men could not account for the smoke that rose from Mount Etna, they told the people that it was pouring from the chimney of Vulcan's forge. In this way all smoking mountains came to be called volcanoes (vŏl-kā'nō)—a word made from the name of Vulcan.

A volcano is a good deal like a geyser. But instead of hurling forth hot water, it vomits steam and ashes and streams of molten rock, which we call lava (lä'vå). The stuff sent out by a volcano gathers in a heap around the mouth of the chimney. It takes the shape of a great cone and grows higher and higher with each new eruption until it may come to be a mountain. Such a cone in Salvador is some 3,000 feet high, and is constantly rising. Yet 150 years ago there was not a sign of it.

The chimney, or pipe, of a volcano often reaches down into the lower part of the earth's crust. It must have started at a point where there was some sort of weak spot in the crust of the earth. Great pressure from below gradually forced the lava up through cracks

Ever so long ago a great mass of molten rock was pushed up from far below the surface of the earth. It probably never actually reached the surface, but contented itself with bowing up the material above it into a hill. Then it froze into hard rock, and gradually the material above it—and part of the great mass itself—was worn away. Nature always wears away the weaker rock first; so this massive tower of hard rock was not worn away so quickly as its surroundings. Bare and furrowed, it is standing to-day in Wyoming. Sometimes the lava-filled "pipe" of a volcano, long since dead, may become a tower much like the one you see here and by the same process.

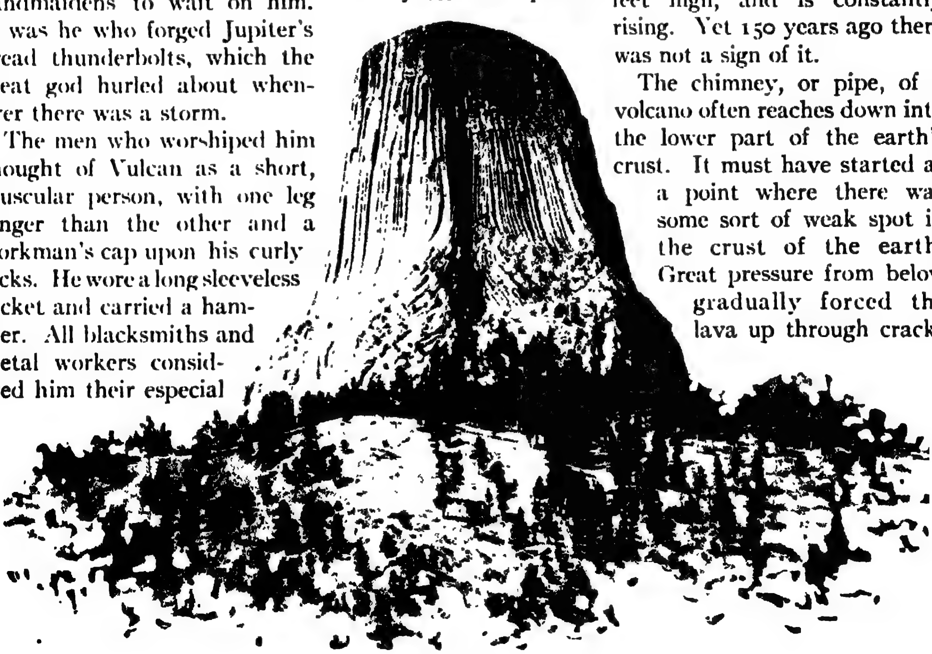


Photo by U. S. Geological Survey

—or "faults"—until it reached the surface; then the lava rushed out through the hole it made, and an "active" volcano began its career.

Often all this happens at the bottom of the sea. Two famous volcanoes, Etna, now on the Island of Sicily, and Vesuvius (vė-sū′vĭ-ŭs), near Naples in Southern Italy, started under the ocean. It is thought that there are a good many on the floor of the Pacific; for many of its islands were once volcanoes.

The Birth of an Island

In 1796 a column of vapor was seen to rise in the North Pacific. Gradually a volcanic mound pushed its head above the level of the sea and formed an island. Six years later a party of hunters landed there and found that in places the ground was still too hot to walk upon. The cone has gone on growing till it has now risen to a great height and is three miles around.

There are a few volcanoes that throw up lava all the time, but most of them do so only by fits and starts. They may sleep for months or years or even for centuries, and then suddenly wake up. Often surface water trickles down into them and is turned into steam. In due time the steam rushes back up the chimney and with loud explosions bursts forth from its prison. When the lava that comes after it has been exhausted, a shower of stones and dust follows and then there is quiet. Often the explosions are so great that they change the shape of the opening, or crater (kra′tẽr), and even destroy the cone itself. Millions of tons of rock have been blown off the summits of volcanoes. The majestic Vesuvius lost eight hundred feet from its crown some hundred years ago.

Ages ago the molten rock sometimes burst through long cracks in the surface of the earth. This happened, for instance, in what is now the valley of the Snake River in Idaho, and the lava that oozed out there hardened into a great plain of basalt (bȧ-sôlt′)—a dense black rock.

Volcanoes used to be much commoner when the earth was young. And this was natural enough, because the crust had not cooled so much then, and was easier to crack. As the earth grows older, volcanoes will probably grow more and more rare.

In the East Indies there was a volcano that had been quiet for two hundred years. You may already have heard its name—Krakatoa (krä′kä-tō′a)—for it made itself famous by suddenly bursting forth in the most tremendous explosion within the memory of man. Krakatoa was a volcanic island lying between Java and Sumatra. In the month of May, 1883, the volcano began throwing up ashes, though not in an alarming way. Suddenly, in August of the same year, a terrific explosion came. The entire top of the island was blown away. For a time it was split in two, like a pair of islands. Then they, too, disappeared.

The explosion caused a gigantic wave, sometimes wrongly called a tidal wave, that swept the neighboring coast, where it drowned 36,500 people and destroyed 300 Javanese villages. It traveled clear around the earth. But even more prodigious was the roar the explosion made. It was heard at a distance of three thousand miles, and in the atmosphere it made great waves that traveled three times around the earth. For three years the air was filled with clouds of dust, which produced the most beautiful sunsets that men had ever seen.

The Pacific's Fiery Garland

There are more volcanoes in and around the Pacific than in any other part of the globe. The Hawaiian Islands were entirely built up by volcanoes, and so were large parts of Japan. On our side of the ocean Mount Shasta and Mount Rainier in the Cascades are old volcanoes long since dead. Mount Lassen in northern California is the only live one in the United States, but Alaska has many, with Mount Wrangell and Mount Katmai the most famous. Mexico too has a large number, and Orizaba (ō′rē-sä′bä) and Popocatepetl (pō-pō′kä-tā′pĕt′l) are gigantic extinct cones. In 1943 a brand-new volcano, Paracutin (pä′rä-kōō-tēn′), was born in a cornfield some 180 miles west of Mexico City and rapidly grew to a height of 1200 feet, destroying seven villages and devastating hundreds of square miles of fertile farmland. It was the first new one in our hemisphere since 1759.

Reading Unit No. 15

WHEN THE EARTH SHUDDERS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What was an ancient explanation of the cause of earthquakes? 1–79
How long does an earthquake tremor last? 1–79
What happens just before an earthquake occurs? 1–79-80
What damage can earthquakes cause? 1–79-81
What was the most destructive of all earthquakes? 1–80
What starts an earthquake? 1–81
How are earthquakes recorded? 1–81-82
How frequently do earthquakes occur? 1–82

Things to Think About

Why is it that not all earthquakes are destructive?
How have earthquakes changed the surface of the earth?
Why are earthquakes more disastrous to cities than to the countryside?
How do the rocks which form in the earth's crust affect earthquakes?
How do earthquake waves travel through the earth's crust?

Picture Hunt

Explain how a seismograph works, 1–81.
What may earthquakes do to cities? 1–79-80

Related Material

What a new mountain is like, 1–19
How have earthquakes affected Central America? 7–44
What have earthquakes done to Sicily? 6–476
How have earthquakes changed the West Indies? 7–55, 64

Practical Applications

How are houses built to withstand earthquakes? 1–80
What should one do for safety when in the country during an earthquake? 1–80

Summary Statement

Earthquakes are caused by the "faulting" of rocks under enormous pressures or by the sliding of rock along a line of weakness or "fault" in the earth's crust.

Photo by Niagara Falls C. of C.

Every year some two million people come from many lands to visit Niagara Falls, one of the wonders of the world. These mighty falls are in the Niagara River, which flows from Lake Erie to Lake Ontario; thus they lie between the state of New York and the province of Ontario. The Canadian and American governments have made the land around them into public parks, so that the beauty of the falls may be protected and visitors may find sightseeing made easy. The falls are divided into two parts, with an island between them. The Canadian Fall, on the side toward Canada, is in the shape of an enormous horseshoe, and so is usually spoken of as the Horseshoe Fall. It measures about 2,600 feet along its curving crest, and is 155 feet high. The American Fall, shown here as it looks from Canada, is 1,400 feet across and 165 feet high.

Photo by N. Y. Central Lines

In the depth of a cold winter the falls of Niagara are almost more beautiful than in summer. It is a strange sight to see all that tumult of waters caught in mid-air, as they are shown in our picture. What domes and pinnacles, and fretted pillars of ice! And what a vast silence. Yet we do not need to wait for the rare occasions when the falls build these temples of snow and ice. We shall find enough to awe us if we stand on their brink in summer and watch that endless green ribbon of water slipping silently over the edge—to break into noise and foam on the rocks below. The falls are very slowly eating backward into the rock at the rate of about four feet a year. No one, of course, knows for how many thousands of years this has been going on, though the falls must date back to the close of the Ice Age, at least 25,000 years ago.

Photo by U. S. Geological Survey

It took man many a day of patient labor to build this street with its complicated houses and drainage systems. Nature needed only a few brief seconds to destroy it all with an earthquake! How easy it was for her to buckle the flat sheets of hard pavement and overturn sound walls of brick and stone!

WHEN *the* EARTH SHUDDERS

A Chunk of It May Slip Somewhere and Set the Whole Ball Trembling

THE ancients used to say that a strong man named Atlas carried the world on his back. Once in a while he would get a sharp pain in the shoulder, as you may imagine! Then he would shift his load, and the people on earth would be well shaken up. Thus the men in early Greece explained the earthquakes that are still so alarming to us. We can imagine an early family sitting around the open fire in a flimsy little hut when suddenly the ground is taken away beneath them. The house falls flat, the flames spread swiftly among the crazy timbers, and lucky it is if no one is pinned beneath the ruin.

An earthquake is well described by the word itself. The ground quakes or trembles. It does not last long—a few seconds as a rule, though rarely it may go on for several minutes. The average time is three-quarters of a minute.

Earthquakes are common enough in certain parts of the world, though most of us are not likely ever to feel one. They begin with a confused murmuring sound, weird and not unlike the sighing of wind in trees or the breaking of waves on the shore. Everything that is loose—dishes, pans, even the heavier furniture—begins to tremble and clatter. Then, if the quake is severe, the

murmur grows to a roar and things begin to crash. One is violently shaken about, as if in a storm at sea. The walls of the houses crack, and often great buildings topple. And then suddenly all is calm. The earthquake is over. It has really been due to the passing of waves through the crust of the earth, which trembles as if it were a mould of jelly on a jolted table.

If you are in the open country when the trembling begins, you will be wise to lie down flat, instead of waiting to be thrown. Get clear of all standing objects if you can, for trees will sway until their branches sweeptheground. Great cracks may open in the earth and close again, and as they close, the air that is violently forced out brings with it clouds of sand and water. And sometimes the noise is stunning.

Photo by Visual Education Service

This is what an earthquake did to the City Hall of San Francisco. The steel frame of the building still stands, but most of its facing of cement and brick was wrenched loose.

It is a common belief that fire is belched from the earth at such a time, but this is not true. The fire which usually follows an earthquake is started from lamps and stoves. None comes from the earth itself.

What an Earthquake Can Do

Earthquakes sometimes swallow up a lake, and sometimes spout great streams of water from the ground. Often, when they take place beneath the sea, they send gigantic waves to wash the shores hundreds of miles away. It is as if a stone the size of a mountain had been plumped into the ocean. Sometimes, though wrongly, these are known as tidal waves, because they once were thought to come from a tide that ran unusually high. Sometimes the undersea quakes are not felt on land, but their force and location are told by delicate instruments.

The first sign of such a wave is the withdrawal of water from the shore, leaving the harbors bare. In a few moments the sea comes rushing back, a towering wall, and thunders inland. Again the water disappears, again it returns. The deadly ebb and flow may last for a number of hours.

Such a disaster once befell the coast of Chile. On that occasion the earthquake had been felt; buildings had even been thrown down. Then the sea retreated from the shore, leaving ships high and dry which had been anchored in deep water. When the sea returned it hurled the ships like chips of wood upon the land. Among them was a United States war vessel, which was carried half a mile inland. She lay there for nine years, and then another wave came along and bore her still further from the shore.

But most terrifying of all is an earthquake in a city. In 1906 one of them left San Francisco in ruins. Whatever havoc the quake failed to work, the fire finished. Great buildings fell, and sent up such clouds of dust that everything was wrapped in a kind of ghostly twilight. Gas lines broke, and the escaping gas took fire and added to the panic. Meanwhile, all telephone and telegraph wires had been broken, and the stricken people were left without any way of communicating with the outside world.

Earthquakes are frequent in Japan, where there are sometimes as many as four in a day, though few of them do much harm. In the fifteen hundred years during which records of them have been kept there, only two hundred quakes have been severe. But the most destructive of all earthquakes occurred there in 1923, when 200,000 persons were killed. The Japanese have devoted a good deal of time to studying the subject and have made some important discoveries.

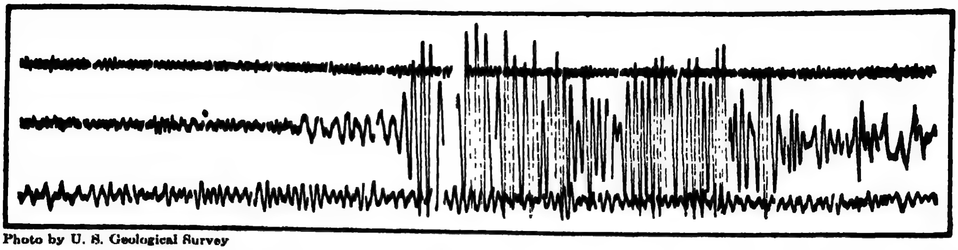
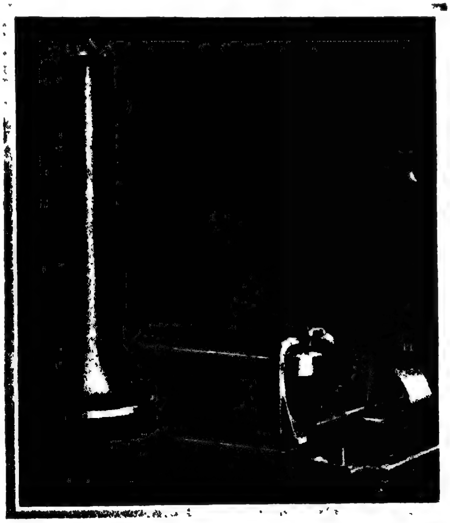


Photo by U. S. Geological Survey

Somewhere, deep in the earth's crust, a colossal movement took place, and in the center line is what the seismograph wrote about it. Three sets of waves told the news. Two of these traveled through the body of the earth, one going at about twice the speed of the other. Since the slower of these two cannot pass through liquids, we know that the bulk of the earth must be solid. After these two sets of waves had brought the news, a third set, which had traveled along the earth's surface, arrived—a bit late, perhaps, but in time to give the needle of the seismograph an extra good shaking and make it write the biggest zigzags.

Over a hundred years ago a series of earthquakes passed over the region of the lower Mississippi River and were felt through the whole of the eastern part of the country. At two o'clock one morning the little town of New Madrid, Missouri, was awakened by a noise as of thunder close at hand and felt a tremendous shock. In a few moments the air was full of sulphurous vapor. People thought it was the end of the world. Mild shocks kept up for months; there were nearly two thousand of them. Many were not severe enough to be felt, but others cracked the earth open in yawning chasms twenty to thirty feet wide and as much as six hundred feet long. Out of these rents great jets of sand and water were hurled up as high as forty feet. Lakes were wiped out and new ones were formed in unexpected places, where they are found to this day. Often they are large; one of them, Reelfoot Lake, is twenty miles long and seven miles wide. From a boat we may look down into the tops of trees that were drowned over a century ago.



Whenever Atlas shifts his heavy burden this clever instrument records the fact. If you have the opportunity you must go to see the seismograph at work in the Museum of Natural History in New York.

Earthquakes have sometimes changed the whole face of a country. Shores have been raised as much as fifty feet or sunk beneath the sea. And in some parts of the globe, where earthquakes often happen, this rising and falling goes on at the present day.

In another story we have told how the mountains of the earth are made. If you have read that, you will remember that vast beds of rock are first laid down beneath the floor of the ocean. Then enormous pressure from the sides may squeeze the layers of rock until they are broken up, or "folded." Later still, the whole mass of rock is pushed up into a mountain, and more breaking may occur. Such breaking, or "faulting," will result in an earthquake. Have you ever broken a stick in your hands and had your hands "sting" as it snapped? The sting comes from the rapid vibration in the two pieces of the broken stick. Just so the broken rocks may vibrate enough to cause the "waves" of an earthquake.

But earthquakes of this kind are probably rare. The break, or fault, that remains in the rock is always a line of weakness; and most earthquakes come from a later slipping of the rock along this line. Along the fault

millions of tons of rock may slip and fall a *few inches or a few feet; and this will set all the crust of the earth around vibrating.*

Most of the earthquakes occur in places where new mountains are being built or where they have recently been raised. The faults have been present there for an unknown length of time, and the earthquake comes when the forces due to shrinking or to uplift cause a slipping.

At this very moment the earth may be trembling mightily in far-away Japan. You and I have no way of knowing it until we see the news in the paper, but at Washington and elsewhere scientists can watch it make a record. They have instruments called seismographs (sīs'mô-grăf) on which all tremors are recorded. You will have no trouble seeing what the last part of the word means. We have it in "telegraph" and "autograph" and other similar words; it comes from the Greek "grapho"—"I write." The first part of the word is Greek also—from "seismos," which refers to shaking. So you see our learned word is really very simple; it means "writing the shaking."

And seismographs themselves are a good deal simpler than one might think. When we are told that seismographs are so sensitive that they record the trembling in the earth made by a passing automobile, we expect a complicated machine which only scientists can understand. But we are pleasantly surprised.

An Earthquake Writes Its Signature

The important part of the device is a highly sensitive pendulum which is set swinging by the slightest trembling in the earth's crust. At the end of the pendulum is a needle which scratches on a smoked glass plate as the pendulum swings back and forth. It is with the needle that the earthquake writes its record. The first tremor of the quake starts a clockwork that keeps the glass plate revolving, so that a clean surface is constantly brought beneath the needle. When the trembling ceases, the clockwork stops. At the first tremor a second clock is likewise started running. It records the exact time at which the quake began, so that if no one *is present when the tremors come, the clock will still tell exactly how long they lasted.*

The mere movement of a person in the room is enough to set the pendulum swinging; so the instrument has to be kept free of contact with the surface of the earth. A deep pit is dug and a pillar of concrete is built from its floor to the level of the earth's surface, but at no place touching the sides of the pit. The seismograph is mounted on top of the concrete column. In this way it is protected from all local disturbances, and rests on the bed rock through which the waves of an earthquake always travel.

But how can the waves be felt if the quake is on the other side of the earth?

Waves through the Earth's Crust

Whenever a portion of the earth's crust slips, it sets up such a disturbance that the vibration travels on and on through the ground in the shape of great waves, very much like the waves that run out in circles whenever you drop a pebble in a standing pool. For though the earth seems so solid, it really is fairly elastic, as anyone must know who has ever felt the jar of a passing train. Indians, with their quick hearing, used to be able to detect a footfall a long way off by putting their ears to the ground. Vibrations too faint to carry through the air will travel through the earth.

So an earthquake may be felt at quite the opposite side of the globe; its waves have traveled at great speed—sometimes as fast as ten miles a second—right through the center of the earth. They travel along the crust, too, but a good deal more slowly. Often the waves that have come through the core of the earth reach us a long time before those that have come around through the crust.

Professor Milne, the inventor of the modern seismograph, estimates that there is a little earthquake somewhere about every fifteen minutes, and that big ones take place about every four days. But even though they are so common, it is very rarely that they disturb thickly-peopled districts.

Reading Unit No. 16

THE BIG HOLES IN THE EARTH

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

On which continent are the finest caves to be found? 1-85

Which is the largest cave? 1–85

What is a sink hole? 1-85

How does water carve a cavern? 1-85

How do volcanoes form caves? 1-85-86

What is the depth of underground caves? 1 86

What are stalactites and stalagmites? 1 86

Which cave is the most famous in the world? 1 87

Things to Think About

In a limestone cave what happens to the water and to the dissolved minerals in it?

Why are most caves in limestone areas?

Picture Hunt

What is a stalactite? 1 86

Why is it dangerous to explore unknown limestone caves? 1–84

Related Material

Inside the earth, frontispiece, Volume 1

Where are the world's most famous caverns? 1–89, 92, 6 476, 480, 488

Caves as primitive dwellings, 11–396

Caves used as tombs and temples, 11 40[illegible]

Prehisto[illegible] art in caves, 11–1-4

Summary Statement

Caves are mostly formed by the dissolving of limestone by underground water, but some caverns were formed by volcanic action.

Photo by New Mexico State Tourist Bureau

This giant dome in Carlsbad Cavern, New Mexico, is sixty-two feet high and eighteen feet in diameter. Think how many millions of drops of water it took to build it! Not everybody can visit a famous cavern like this one, but there may be caves well worth exploring right in your own neighborhood—particularly if you happen to live in a "limestone country." Cave exploring is very fascinating; but remember that it can be extremely dangerous! You never know when you may come to a deep pit or a crumbling layer of rock. Be sure to wear shoes that will not slip on wet rock, and carry flash lights, candles, and matches.

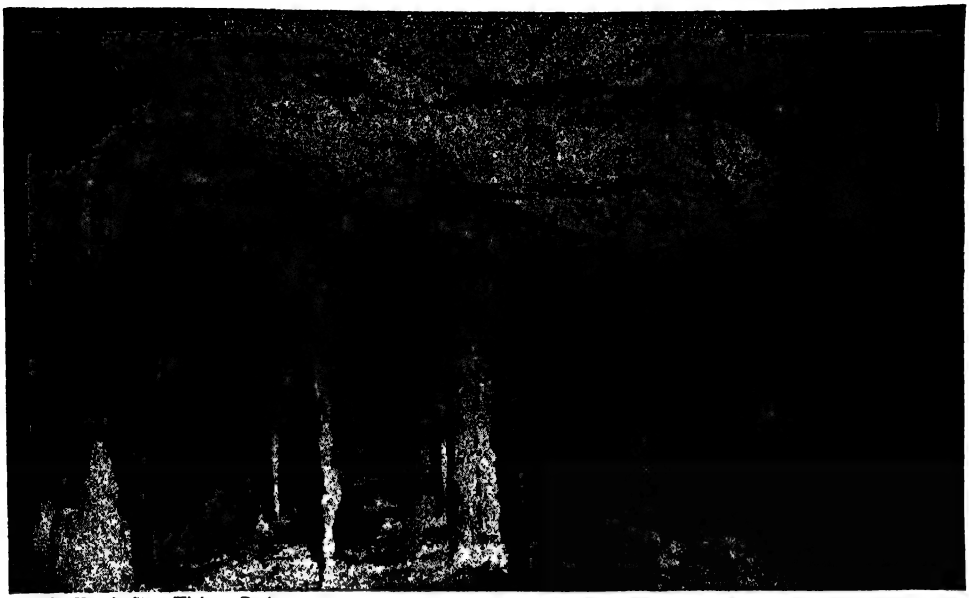


Photo by Nevada State Highway Dept.

Near Ely, Nevada, are the Lehman Caves, now a National Monument of 640 acres. They were carved out of solid limestone by the ceaseless drip of water, and dripping water built those delicate columns.

The BIG HOLES *in the* EARTH

How Little Drops of Water Have Carved Out Halls and Palaces of Marvelous Beauty in the Rock

HARDLY any of the wonders of Nature are more interesting than her caves. In them our forefathers made their homes; and we still find them more curious in formation and more mysterious in beauty than almost any other thing that Nature has made. The finest are in North America, most of them in the United States, which probably has more large caves than any other country in the world. Some ninety of them, large and small, honeycomb Edmonson County, Kentucky. The Mammoth Cave there is the longest in the world. Carlsbad Cavern, New Mexico, has the largest rooms.

Mammoth Cave was discovered in 1809 by a hunter who followed a wounded bear into it, but it was not explored until a party went through it looking for saltpeter to make gunpowder in the War of 1812. The cave is really ten miles long, though there are some 150 miles of winding passages. Its greatest width is three hundred feet.

All around it the ground is punctured with deep holes—sixty thousand of them—where the water has dissolved away the limestone. As it sinks into the earth through cracks, the water slowly eats away the limestone around the crack until an open channel is formed leading underground. This is called a sink hole. One at Green River, Kentucky, is two hundred feet deep.

Water seeping underground through the joints and crevices in limestone sometimes meets a different layer of rock which it cannot dissolve. It then has to eat its way to the sides in the limestone on top of the other rock. In doing so, it carves out caves and narrow passages, which after thousands of years may grow to be as large as Mammoth Cave. Big caves are always formed in this way; and that is why they are usually found in limestone rock. Whenever caverns have been hollowed out by waves along a coast, they are much smaller. In volcanic regions

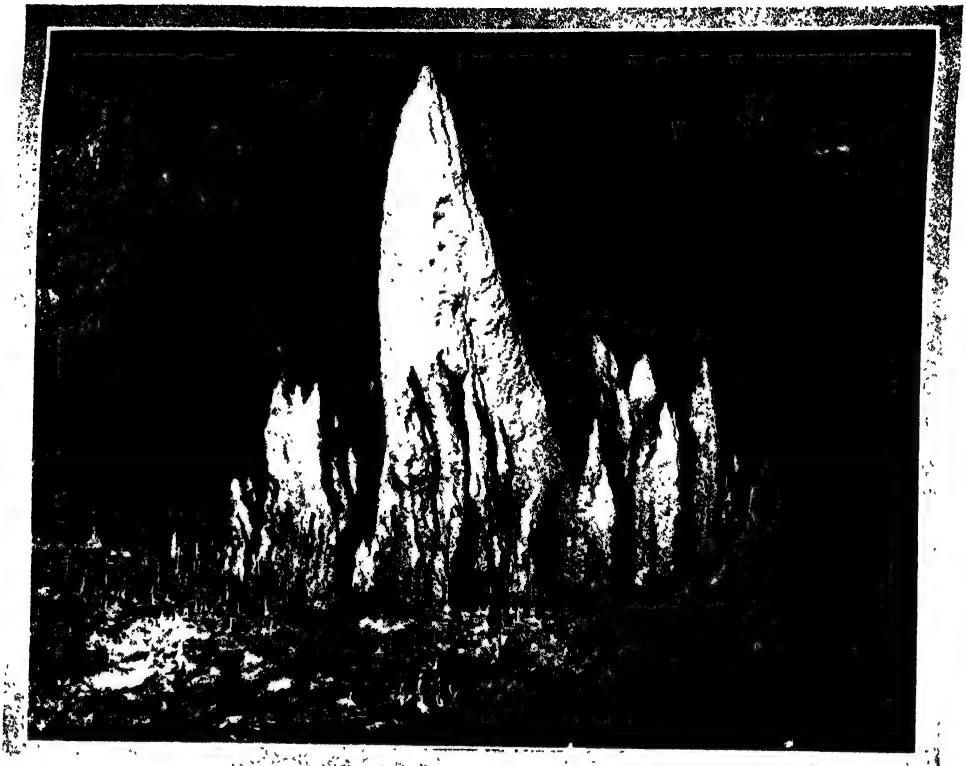


Photo by L. & N. Ry.

No one would care to go barefoot on this prickly floor in Mammoth Cave! These stalagmites, large and small, have all been made by the constant drip of tiny drops of water carrying minerals in solution.

they are even formed by lava and molten rocks, as has happened in the Azores, in the Canary Islands, and in Iceland. Everywhere weathering has helped to widen and deepen them, and man, too, has enlarged them. Often it is hard to say how much has been done by man and how much by nature.

The Great Cave at Carlsbad

At Carlsbad, New Mexico, is one of the largest and deepest caves in the world. It goes down 1,350 feet below the surface, and has rooms as much as 4,000 feet long and 350 feet high. These great halls are incrusted with the most exquisite lacework in glistening stone.

Many caves are splendid to see. Great crystal pillars hang like icicles from the roof and rise like columns from the floor. Those hanging from the roof are stalactites (stȧ-lăk′tīt), and those rising from the floor stalagmites (stȧ-lăg′mīt). They are made in much the same way, for one is formed on the roof by the water dripping from it, and the other is built up on the floor by water dropping on it.

How Caves Are Turned into Fairyland

But how can water make icicles without freezing? As it seeps through the limestone roof of the cave, it dissolves away part of the lime that such rock always contains. When a drop gathers slowly on the ceiling, part of it evaporates and leaves its lime behind, and the rest splashes to the floor below. Meanwhile, more water gathers. And so each drop evaporates enough before it falls to add its tiny film to the great icicle of a stalactite it is helping to build.

But the water that drips to the floor leaves its bit of lime there too. At first there is no result that you or I could see. It takes a

Photo by C. O. Buckingham Co.

No wonder people have associated caves with the fairy folk! The "Grand Ball Room," as this cave in Virginia is called, would make an enchanting place for gnomes and fairy sprites to dance.

very long time for the drip, drip, drip to build even a tiny knob. The whole stalagmite may take many centuries. But at last the pillar may be raised so high that stalactite and stalagmite join to make a single gleaming column as much as fifty feet tall and reaching from floor to ceiling. No wonder such a cave looks like a fairy palace!

Perhaps the most famous cave in the world is the Blue Grotto on the island of Capri, near Naples in Italy. It will be worth our while to pay a visit there. The only door is by way of the sea. We are a very small party, for the boat that carries us must make its way through an opening only three feet wide and five feet high. Indeed, we have to lie in the bottom while the boat squeezes through the hole, for the little craft is rising and falling with the swell of the sea. Our boatman finds it hard to get us in at all, even on a calm day.

The Magic of the Blue Grotto

Once inside, we are dazzled by the strange silvery-blue light. Everything that touches the water is turned to silver, even the boatman's oars. He plunges overboard and dives for coral. How amazing to see the swarthy Italian suddenly clad in gleaming metal! But the reason for it is simple enough. Underneath the water is a second entrance to the cave. It was probably the door at first, and the entrance we have come through must then have been a window higher up. A flood of sunlight enters the cave through the broad under-sea passage, but in passing through the water it is amazingly transformed. All its bright golden rays are filtered out and only the blue ones left. They are reflected back and forth by the white walls of the cave, which they tint a lovely blue. And the filtered sunlight turns everything in the water to silver.

Legends of the Blue Grotto

There is still another entrance to the cave, but no one has ever been able to explore it. Legend says it led to a great Roman palace. The Romans certainly knew the Blue Grotto, but their descendants were frightened away by stories of witches that haunted it. The tales were doubtless told by simple fishermen alarmed at the sound of waves booming in the cave; but people believed them and kept away. As a result, the beautiful grotto was forgotten until about a century ago, when an artist and a poet found it again. Their boat could not get in, so they had to swim through the narrow door. What a sight burst on their eyes! Later the famous story teller, Hans Christian Andersen, wove one of his fairy tales around the cavern.

In the soft limestone of Capri the caves are almost beyond numbering. There is a White Grotto, a Green Grotto, and a Red Grotto. But whatever the color, it has come from sunlight filtering through the water in the way we have described.

Reading Unit No. 17

RIVERS BENEATH THE EARTH

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the origin of a spring? 1-89-90

How is the earth's water supply renewed? 1-89

What is the greatest depth at which water can be found in the earth? 1-89

What is the annual rainfall in the United States? 1-89

What is a well? 1-90

What is an Artesian well? 1-90

How do minerals get into spring waters? 1-91-92

What is an underground lake? 1-91-92

Things to Think About

What would happen to the earth if the water which boils away or evaporates disappeared from our planet?

Why does water flow from Artesian wells without the aid of pumps?

What is the life story of a lake?

What happens to a lake when underground springs stop flowing?

Picture Hunt

What is the source of supply for an Artesian well? 1-91

What is a "dowser"? 1-91

Related Material

What is the importance of water to plant life? 2-193, 197

How much drinking water is necessary for good health? 2-420

The Ice Age, 1-60

The big holes in the earth, 1-85

Practical Applications

Where should an Artesian well be drilled? 1-91

Why are some mineral springs believed to be important to health? 1-90-91

Why are Artesian wells better than dug wells? 1-90

Leisure-time Activities

PROJECT NO. 1: Make a working model of an Artesian well, 1-91.

PROJECT NO. 2: Make a chart of the geologic structure of the land surrounding an Artesian well, 1-91.

Summary Statement

Underground water supply prevents the wiping out of life during periods of drought.

Photo by L. & N. Rail

This is the famous Echo River, in Edmonson County, Kentucky. It winds its way through mysterious channels far below the surface of the earth. Its walls echo back sounds which seem to come from all directions—like the voice of the sibyl, which re-echoed "in rushing murmur" through the caves of ancient Cumae.

RIVERS *beneath the* EARTH

How Does the Water Get into a Well or Make a Lake on Top of a Mountain?

HAVE you ever wondered how the water that trickles from a roadside spring found its way into the earth? The little natural fountain is a part of countless tons of water that are always flowing underneath our feet. If it were not for those hidden supplies, people in many parts of the world would die of thirst during long droughts, when all the water on the surface dries up.

But though we depend so much on water from underground, it has all come, to start with, out of the sky. Rain and melted snow trickle down through cracks in the rocks and soak through the soil. A certain amount may go down a long way, though no one has ever dug deep enough to see how far. Most of it stays near the surface; in mines there is very little water below a few thousand feet.

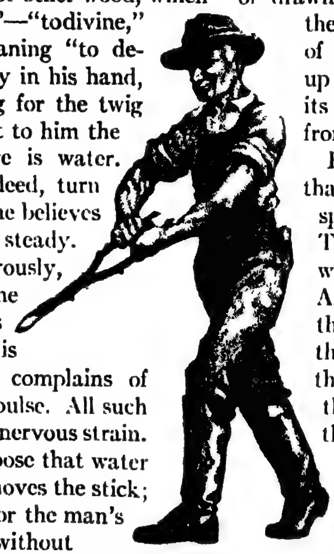
Not a drop of water can ever be completely destroyed. We may boil it away or the sun may dry it up, but that only means that it has taken another form and turned to steam or mist or cloud. Somewhere it still exists, and sooner or later it will fall back to the earth again as water.

It is amazing how much the heavens send us. If the whole amount of water that falls on the United States in a year were gathered together it would fill a tank containing fifteen hundred cubic miles. Imagine the weight of it! For when only an inch of water has fallen over a square mile, the earth's crust has to bear up under an added weight of over 425,000 tons.

Wells have always been exceedingly precious to mankind. Even in our own day of city waterworks, millions of people who do not live in towns rely on wells for their supply of water. They are expensive to dig, especially if one has bad luck in finding a supply of fair size as he goes down. So people have tried all sorts of ways to find out where the

water would probably be found. One means of locating it was known as "water divining." The custom, as you will see, belonged to days before the development of science; but in outlying parts of the country it still lasts and there are still a certain number of people who believe in it.

The man who tries to find out where the water lies is called a "dowser" (douz'ẽr). He carries a prong of hazel or other wood, which is called a "divining rod"—"todivine," in this connection, meaning "to detect." Holding it gently in his hand, he walks about, waiting for the twig to turn and so point out to him the spot under which there is water. Often the rod does, indeed, turn in his hand, even when he believes that he is holding it steady. Sometimes it turns vigorously, and may even strike the dowser's body. He is quite exhausted after his efforts, and sometimes complains of sickness and has a high pulse. All such symptoms are a result of nervous strain.



This odd fellow, who strides along clasping his forked stick tightly in his hands, is a "dowser." Where his stick turns and points to the earth, he expects to find water. Others of his profession think that their sticks have the power to locate buried treasure and underground passageways. How pleasant it would be if their belief were only true!

It is ridiculous to suppose that water far underground really moves the stick; but it is quite possible for the man's own muscles to turn it without his meaning them to do so. One is forced to believe in the latter explanation. Many people have acted as dowsers and have made honest attempts to see if the stick would turn. Some have even been convinced and have become professional dowsers. But a scientific observer has to conclude that they are all deceived. The turning of the twig is due to unconscious acts of their own, brought about by their squeezing the stick. It is a trick played upon them by their own brains and nerves.

Where Do Springs Come From?

We must not picture underground water as rushing along in great tunnels. It works its way slowly through sand, gravel, and other loose stuff. When we sink a shaft down to one of those levels, the water gently flows into the shaft and we have what is commonly called a well. Sometimes a "vein" of water is driven along by the weight of a column of water behind it. If it meets a crack leading upward, it may be pushed to the surface, where it appears as a spring. Sometimes the water from springs gathers in low basins and forms lakes. More often it helps to form a stream.

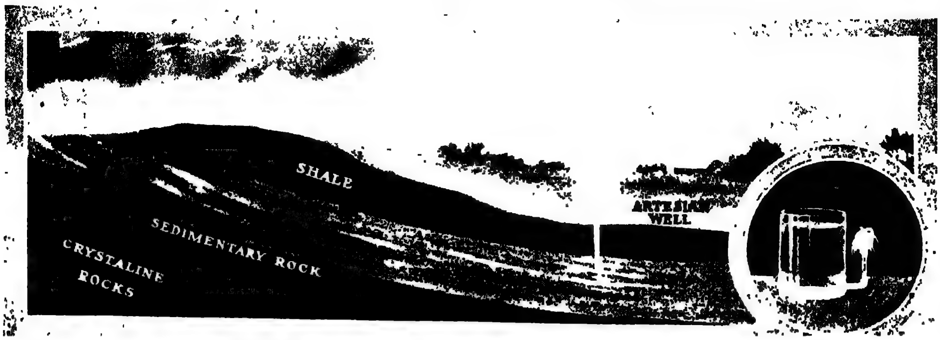
From most wells the water must be pumped or drawn with a bucket. This is because there is not enough pressure, or weight of water behind, to force the column up to the surface. Water will not, of its own accord, rise above the level from which it started to flow.

But in many places there are wells that flow like fountains, sometimes spurting high above the ground. They are called Artesian (är-tē'zhăn) wells because of the famous ones at Artois (år'twä'), in France, where they have long furnished water to the people. The underground waters that feed an Artesian well may enter the ground many miles away from the spot where the well is sunk—and always at a higher level. Like all "water veins," the bed through which the water flows is made of porous matter and surrounded by solid rock.

Suppose such an underground bed reaches from a lake on a mountain top to a valley five hundred feet below. If we sink a shaft in the valley at a point to tap the bed, the weight of the column of water five hundred feet high will push the water below up the shaft and send it high above the ground. The solid rock which incases the bed of porous sand acts as a pipe and prevents the water from escaping in any other direction than up the shaft.

There are many Artesian wells in the Mississippi Valley.

At certain places, such as Saratoga Springs in New York State, Bath in England, and Baden-Baden in Germany, there are springs of mineral water which are highly prized in treating various diseases. People come from near and far to drink from them and bathe



This diagram shows you what makes an Artesian well. First there must be a bed of porous rock that comes to the surface at a higher level than the well and at a place where there is water—perhaps many miles away. This porous bed, which is often sand or sandstone, must be covered by a layer of rock through which water cannot pass—in this case, shale. Then if a well is driven at the level shown, the water will flow like a fountain because of the weight of the water above. The principle is illustrated in the inset.

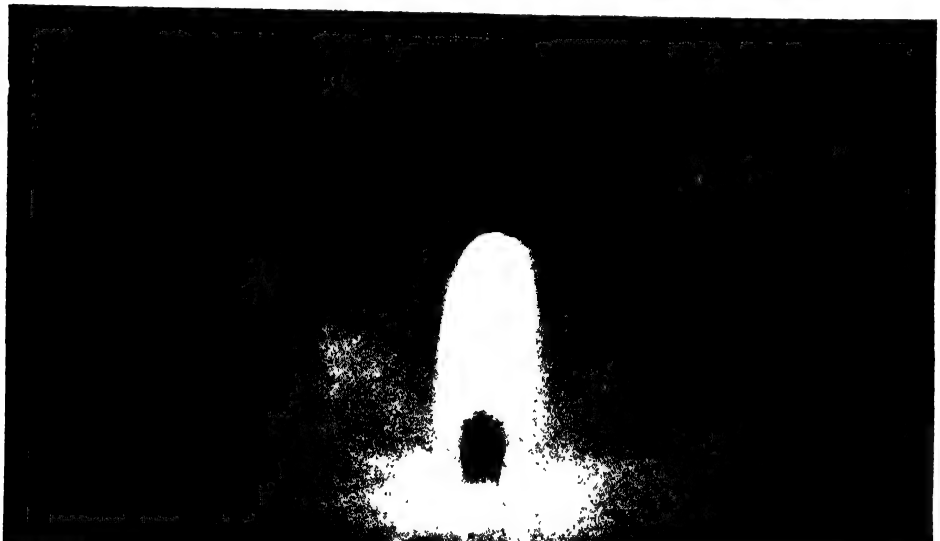


Photo by Colorado State Agricultural Experiment Station

The ancient Greeks would have thought that this gushing Artesian well must have been caused by a touch of Neptune's trident, or by a glancing blow from the hoof of winged Pegasus!

in them. The idea is not a new one. The ancient Greek physicians were great believers in the curative powers of mineral waters, and the Romans discovered and improved some of the springs that are still among the best in the world.

How Water Gets Its Minerals

It is clear that the water must pick up its minerals from the earth it passes through, for there are no minerals in the rain and snow that fall from the sky. Iron, sulphur, lime, and various other substances are dissolved out of the rock and sand as the water passes through, the kind of minerals it contains depending on the kind of soil through which it has trickled. Often mineral springs are very cold, but sometimes their waters have been warmed by heated rocks under the earth. Such is the case in the famous springs at Bath, in England.

The work of water in chiseling away the surface of the earth may be studied everywhere by anyone with eyes to see; but only

a few of us have a chance to explore the famous Echo River, which flows under Edmonson County in Kentucky.

In certain places this strange underground stream runs gently and may be explored in a small boat. At other places the current is swift and completely fills its tunnel. But for half a mile visitors may ride over the clear waters and marvel at the weird scenery. The lofty roof of limestone and the many branching avenues and caverns serve as reflectors for sound. Every syllable is tossed about and about till it is hard to say where it comes to rest. No one can hear those whispers from unseen halls without awe. "Echo" is indeed a fitting name for the mysterious hidden river.

Lakes beneath the Ground

There are many underground streams in the world, and some of them even have waterfalls. They sometimes gather into lakes, one of which it was found possible to measure; it was 250 feet long and 150 feet wide. There is a source of water known as the Bottomless Fountain which clearly must be connected with such an underground lake, for the spring throws up living fish.

In Florida there are two lakes several miles apart which rise and fall together. One answers the mood of the other as quickly as our right eye waters when we get a cinder in the left. It is thought that an underground river has slowly worked its way through the ground and now joins the two lakes.

We have seen that lakes may get their water from underground—from little springs or hidden lakes and rivers. But though springs often enter them and help to keep them alive, most lakes get their water mainly from the surface. Rivers and little brooks bring it. So the lakes are not long-lived in the world's history. As compared with the millions of years that the earth has been here, they seem to last but a moment.

For often the streams and rivers that feed a lake change their courses, or the outlet is deepened by the stream flowing out, until the lake is drained away and dries up. Sometimes it is slowly filled with sand and mud brought down by the streams that feed it. Lilies begin to grow in its still, shallow waters. Then come sedges—grasslike plants that grow in marshy spots. As time goes on, more soil is dumped there by the busy streams and finally the seeds of trees take root. Years pass; man fells the trees and saws them into lumber to build himself a home. What was once the bottom of an ancient lake may now be sown with grain.

This is the picturesque death that overtakes all lakes. The time will come when those now in existence will have passed away. But new lakes are always being formed. When the ones that now ripple in our valleys are gone, others will have been born elsewhere to take their places.

Many of our lakes were formed during the great Ice Age. Glaciers (glā'shēr), or fields of moving ice, crept over the earth's surface, deepening canyons and carving up hills and valleys. The soil and rocks which they pushed along made dams at the ends of canyons that the glaciers had followed. When the great ice field melted, its waters gathered behind the dams and formed lakes. There were no Great Lakes in North America before the Ice Age. Where they now lie were broad valleys and streams.

A Mammoth Lake of the Ice Age

Geologists can tell us when a lake appeared and what changes it may have gone through. They know, for instance, that one large lake, which they have named Algonquin, more than covered the present sites of Lake Superior, Lake Michigan, and Lake Huron. This came with the Ice Age. Gradually, as the ice withdrew, the water level was lowered until, in place of one vast lake, there were three smaller ones, as at present.

It is not glaciers alone that have shaped the basins of lakes. Movements of the earth's crust are responsible for a great many of them. The Dead Sea, in Palestine, occupies a "fault" basin, formed by the cracking and slipping of great blocks of the rock floor. It has the distinction of being the lowest lake in the world, for its surface is 1,300 feet below sea level, and its bottom 1,300 feet lower still.

Reading Unit No. 18

THE SOIL THAT FEEDS US

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How are dust and sand formed? 1–95
Why does sandstone disintegrate? 1–95
What chemicals found in water and air attack rocks? 1–95
What is rust? 1–96
What is clay? 1–96
What is fertile soil? 1–97
What do plant roots do to rocks? 1–97
What is humus? 1–97

Things to Think About

What would happen to life on the earth if the soil vanished?
What would happen to soil if animals and plants left no remains when they died?
What is the fate of all living matter?
What would many farms be like to-day if the glacier had not moved over the land?

Picture Hunt

How is a natural bridge formed? 1–96
How is desert sand changed into soil? 1 95

Related Material

How does soil affect our food supply? 2–41
How does the chemical content of soil affect plant growth? 2–45
How do bacteria help the soil? 2–18
How do lichens help make soil? 2–80
How does fertilizing the soil help plants? 2 45
How is soil improved on truck farms? 9–153
How are silkworms used to fertilize the soil? 9–44

Practical Applications

How do rivers often affect farm land along their upper courses? 1–97
Why should worms, beetles, and ants be protected? 1–97
How may desert sand be turned into soil? 1–95
Why are some plants plowed under? 1–97

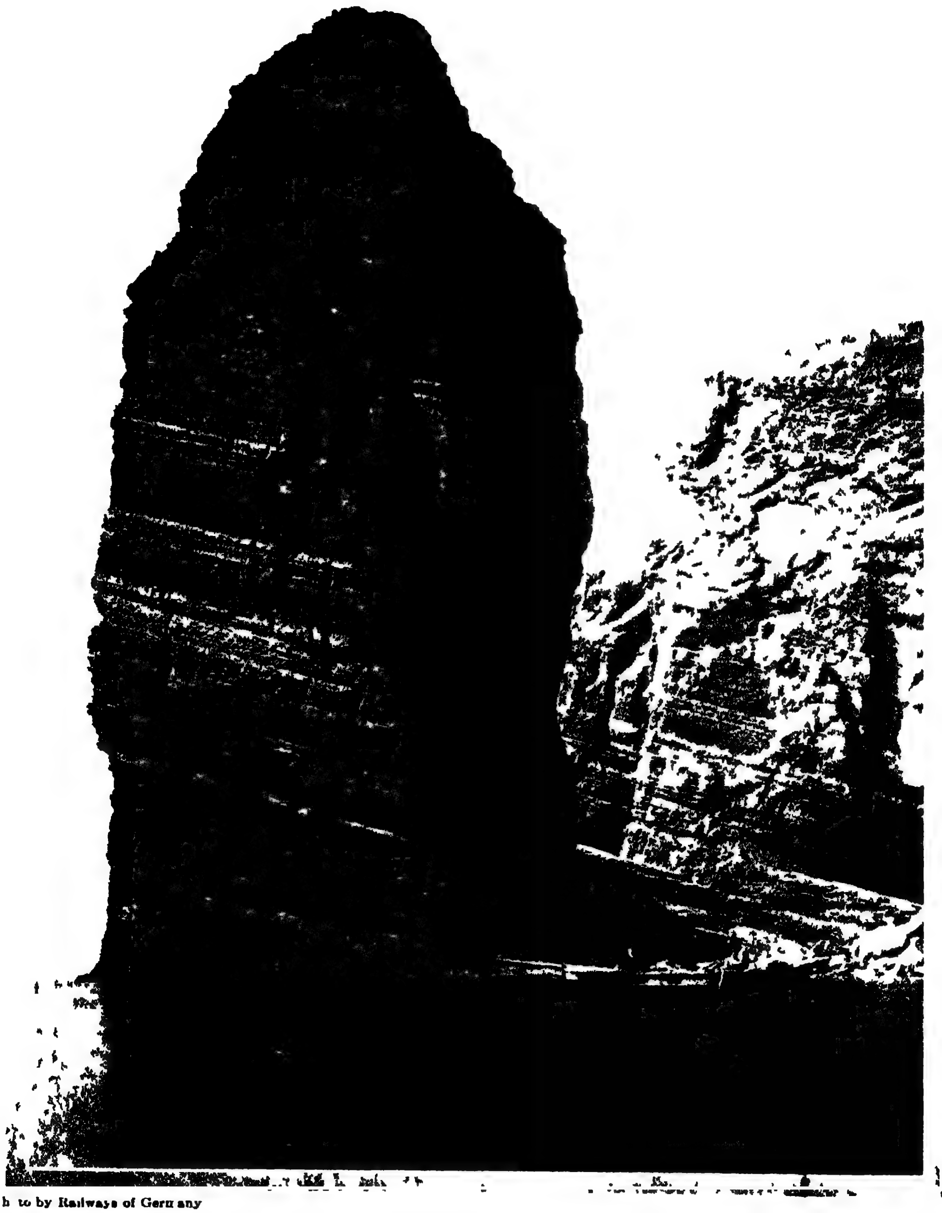
Leisure-time Activities

PROJECT NO. 1: Plant seeds in clay, sand, and soil, and watch the growth of the plants.

PROJECT NO. 2: Make soil by combining sand, clay, and humus, 1–96-97.

Summary Statement

The soil we need to grow our food supply is a mixture of sand, clay, and humus.



Ih to by Railways of Germany

Grain by grain giant rocks like these give themselves up to the persistent waves The sea will re-deposit them somewhere else, and many of them will eventually go to make up soil on which green grass will grow. These rugged battlements, bright red against a background of white sand and jade-green sea, are part of an island lying off the coast of Germany On this side of the island, where the tilted beds point toward the sky, steep cliffs have been formed, on the other side the beds slope gently into the water

Here is some of the raw material out of which soil is made. If you were to add water and humus to the sands of this barren California desert, you could "make the desert rejoice and blossom as the rose."

The SOIL THAT FEEDS US

All the Food We Eat Comes from the Ground to Start with, and Gets Its Substance Out of the Good Brown Earth

WE HAVE heard of all the ways in which winds and waves and weather are at work to tear down the solid rocks and turn them into dust and sand. Burning heat and bitter cold make even stone expand and contract, and so fill it full of little cracks and crevices. Then water seeping in dissolves away part of the solid rock material, such as the lime in limestone. And when the water freezes it expands—and cracks the stone just as surely as if the moisture had been dynamite. In the end the solid rock is turned to powder.

Sandstone is largely made of little hard particles of quartz, or silica (sĭl'ĭ-kȧ), a substance from which glass is made. They are all cemented together with carbonate (kär'-bŏn-āt) of lime. But lime dissolves in water. So after the steady drip of centuries only the little gritty particles of silica are left, to blow about as sand.

Then the wind takes a hand. It whips up the loosened grains and uses them as a sand blast to file away the rocks still more. For the grinding power of sand is very great. It will wear through window glass in a few months.

Chemicals, too, in the water and in the air, eat up the substance of which the rock is made. For instance, carbonic (kär-bŏn'ĭk) acid gas, which may be found in water, attacks certain rocks and leaves them powder.

Photo by U. S Geological Survey

When Nature plucks out of her aged rocks the tiny grains that will help to build up soil, she often makes strange structures in the process. Here is Edwin Bridge, a natural bridge in Utah.

Oxygen in the water unites with iron in the rocks to form a substance that is entirely different from either one alone. Chemists call it iron oxide, but you and I call it rust. In the making of it the solid rock has been forced to yield up its iron, and only dust is left.

How the Soil Is Made

And then the rain washes the sand and dust from the hilltops into the valleys and piles it there in layers. Wind blows it into drifts. Landslides and avalanches dump it about; ocean waves pound it fine. And a great glacier, happening by during a stretch of thousands upon thousands of years, crushes and grinds and wrenches till a lofty hill is scraped away and an area as big as a farm is picked up, kneaded, and dropped down again a hundred miles farther on. Gradually pretty much all the dry land in the world is covered over with powder.

It is this powder that we call the soil—and without it you and I would never have been born. Without it humankind could never have come to live upon the earth.

Now there are different kinds of soil, and not all of them are fertile. Sand alone will not grow much, as you must often have noticed. Dust alone, while better than sand, is not very productive; and it can be a great nuisance. In soil it is known as clay, and clay, because water cannot drain through it readily, gets very sticky when it is soaking wet. The best soils result from a mixture of clay and sand; we call it "loam."

But just loam is not enough to raise good crops. It is the presence of something else still that makes the soft earth fertile.

Life That Helped to Make the Soil

Millions of years ago, when our great round world was still quite young, that mighty, mysterious thing we know as "life" in some way came into being. We do not know how or where it first appeared; we do not know just exactly what it was like. But we think it first took the form of tiny growths in the sea. These changed and multiplied and grew more and more complex. Grad-

ually the hundreds of new forms spread up over the land, as tiny animals and plants. And whenever they died, their lifeless bodies went back to Mother Earth—adding a kind of substance entirely different from the rocks and sand and mud which were all that had gone to make up the solid ground before. Finally plants with tender little roots began to grow. But those tender roots, twining about in the earth, exerted the amazing pressure of two hundred pounds to the square inch of surface. With gentle fingers they cracked the huge bulk of the rocks as easily as you would pull apart the petals of a flower. The acids the plants contained ate away at the stone; and when the little plants died, their bodies went back to the earth again.

By the time the higher animals came into being, the face of the earth had been green for a long, long time. Earthworms and beetles and ants had done their bit by stirring the soil and preventing its getting hard, and then, in dying, had given their bodies back to it again. And as the bodies of plants and animals decayed, they were changed into substances that served as food for more growing animals and plants.

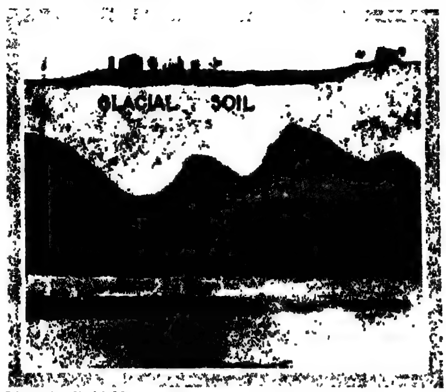


Photo by Field Museum

Most of the world is covered with vegetation. Beneath this you will find loose material—such as clay and sand—varying in thickness from a few inches to many feet. This is known as "mantle rock," and the uppermost part is what we call soil. In many places you will find that the mantle rock came from the decay of the underlying rock, for it will grade into the rock imperceptibly. But where glaciers have been, you will often find that the mantle rock has nothing to do with the bed rock. The ice scrapes off the loose material, leaving a bare rock floor. Then, as the diagram shows you, the glacier may bring material from somewhere else and deposit it on the bed rock.

And those are the substances that make a soil rich. We refer to them as humus (hū′-mŭs). Whenever soil contains a great deal of humus—decaying plant and animal matter—it will grow fine crops. Such a soil is usually dark in color. For though its original shade depended on the color of the rocks from which it had been made, an abundant supply of humus always turns it darker.

Sometimes rivers, such as the Nile and Mississippi, deposit rich black mud that they have stolen away from lands hundreds of miles upstream and have carried down to their lower reaches. That is known as alluvial (ă-lū′vĭ-ăl) soil; it is sometimes the richest in the world.

Soil may be enriched by adding farmyard and other natural manures, or chemical fertilizers containing nitrates, phosphates, or potash. The last is a strong alkali used both as a fertilizer and in making gunpowder. New Mexico has enough potash-bearing ore to supply all our needs. Phosphates are mined largely in the United States, with Florida and Tennessee leading. They are also found in Russia, Algeria, Tunisia, and on certain Pacific and Caribbean islands. Nitrates are manufactured.

Reading Unit No. 1

THE RIDDLE OF THE SKIES

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Why is the year divided into months? 1–100

What is meant by an astrologer? 1–100

Who was Galileo? 1–100

Who was Copernicus? 1–100, 103

What was the Ptolemaic theory of the universe? 1–101-2

What is meant by the universe? 1–102-3

Who invented the telescope? 1–103

Things to Think About

How did the theory that the world is round affect the history of the Western Hemisphere?

How did astrologers both advance and hold back the progress of civilization?

Which astronomers are known as the giants of astronomy?

How different would world history have been if we had kept the ancient beliefs about the universe?

Related Material

What is an astronomical clock? 10–465, 468

Why do eclipses of the moon and sun occur? 1–116-18, 125-26, 204

How do the stars give us the correct time? 10–459-73

How does the moon affect our oceans? 1–9, 133, 135, 137, 9 442

What is the origin of the names of the months? 1–124, 10–477, 478, 480-83

Practical Applications

How is the year determined? 1–100

How was the moon used as the basis of a calendar? 1–100

Leisure-time Activities

PROJECT NO. 1: With the aid of star maps, locate some important constellations of the heavens, 1–170.

PROJECT NO. 2: Watch the moon for a number of nights and make drawings of its changes in shape, 1–124, 126-27.

Summary Statement

Astronomy became a science when men began to observe the stars in order to understand them, rather than to use them for the purpose of predicting human events or of producing miracles.

When the first men, with minds so dim and eyes so keen, looked at the spangled sky, they no more knew how to account for it than a little child knows how to account for wind and the falling rain. No wonder they made up strange tales to explain what was going on overhead! That was the only "science" men had.

The RIDDLE *of the* SKIES

From the Earliest Shepherd to the Latest Scientist, Man Has Found His Grandest Puzzle in the Stars

THE first man must have gazed upon the stars with the same wonder as you and I. What were those mysterious lights, so vivid yet so calm? Were they pinholes in a great curtain drawn across the heavens every night? Were they the homes of the happy dead? Were they shining palaces where the gods sat and spied on the men down below? Every race and every tribe wove its own myths about the heavenly bodies, but nearly all the races worshiped the sun and moon as gods, and were full of awe at sight of a falling star or an eclipse.

Yet the labor of learned men for many centuries has now taught us more about the far-off stars than we know of many things right at our door. So when you have finished reading this, you will feel that sun and moon and all the starry hosts are good and familiar friends.

We cannot fix a date for the beginning of astronomy (ăs-trŏn'ō-mĭ), the science which treats of the heavenly bodies. As far back as our history goes men were studying the stars and watching the order of the seasons. For when man first gave up a roving life and settled down to cultivate the soil, he had to find some way of telling when it was time to sow and reap. It would not take him long to notice that when winter came the sun was lower in the heavens and the nights longer, or that, as spring advanced, the sun rose and set farther and farther north on the horizon. Thus the calendar began.

It is very likely that the first astronomers were humble shepherds, who had plenty of time to watch the stars as they tended their sheep on Asiatic hill and plain. During the long still nights they watched the moon, and as they waited eagerly for her return, they counted the days until the first appearance of her crescent. They made it almost thirty—a period of time we still know as a "month." Later they learned to count the time it took the sun to travel from his highest place in the heavens—which later peoples called Midsummer's Day—south and back again to his point of starting. This was a "year"; it still remains the unit by which we measure time. Of course they did not realize that this seeming journey of the sun was really due to a change in the position of the earth as it journeys through space.

Of late years astronomy has made amazing strides. This is partly on account of the magnificent instruments that scientists have at their command. In an age when the most accurate timepiece to be had was the little hourglass, one could hardly expect this old astrologer to foretell to a second the time of an eclipse.

It was in China, Egypt, and Babylonia that the first real knowledge of the stars grew up. Of course the early observers took the earth to be the center of the universe and thought it was much larger than any of the bodies they saw in the sky. Naturally enough, their chief interest lay in finding out just what the actions of the shining lights above them had to do with their own fate. This led to the growth of a kind of false astronomy, a system of magic which we call astrology (ăs-trŏl'ō-jĭ)—the supposed art of reading the influence of the stars in human affairs and of foretelling events by them.

Who Were the Astrologers?

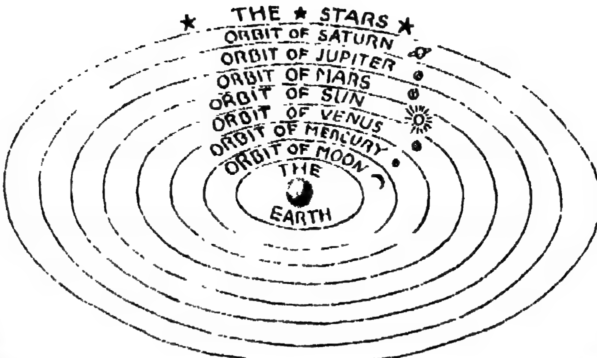
Not many people now take stock in this outworn belief; but the observations of the old astrologers were of great help in adding to our knowledge of the heavens. Appointed by the rulers to positions of high honor, they spent their whole time noting down the motions of the stars and planets and mapping out the heavens. And crude as were their early charts, the patient labor spent on them was of great value in the progress of the science.

But the astrologers came to be sad rascals. The ignorance and superstition round them encouraged them to stoop to every kind of humbug. They sank into mere fortune tellers, who tricked people into believing that they could foretell the future. They even made a pretense of practicing medicine, for it was thought that the stars could control the various organs of the body.

It was a great misfortune for the science to fall into such bad company. For while astrology flourished, astronomy was laid on the shelf. No effort was made to push on in the study of the universe. Indeed, the subject really came to have an evil reputation, and like many other sciences it had for centuries to make its way against misunderstanding and abuse before it reached its present place of honor.

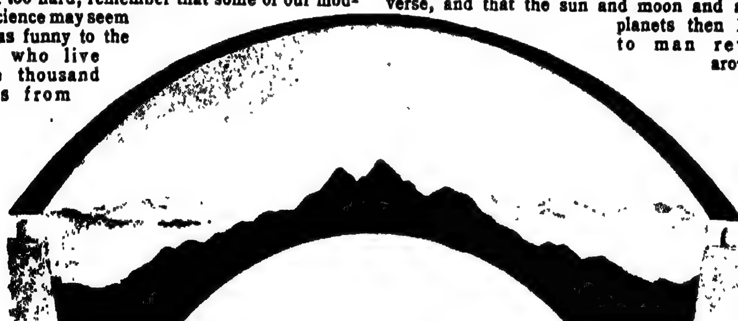
Copernicus Upsets a Science

One of its desperate battles was with ignorant beliefs and superstitions. Men were burned at the stake for saying that the earth was merely one of the planets, and Galileo—who was born in the same year as Shakespeare, 1564—was thrown into prison for supporting the views of Copernicus (kō-pûr'nĭ-kŭs), who said that the earth is not the center of the universe, but travels round the sun. Those were dark days, and astronomy made slow progress in them.

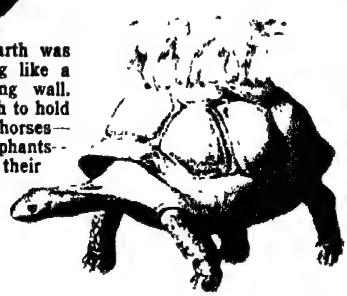


On this page are pictured four of the many explanations devised by ancient man to explain the universe. Three of them, at least, will seem funny to you. But before you laugh too hard, remember that some of our modern science may seem just as funny to the men who live three thousand years from now.

Above is a map of the universe as worked out by the Egyptian astronomer Ptolemy, in the second century after Christ. You will notice that the earth is the center of the universe, and that the sun and moon and all the planets then known to man revolve around it.

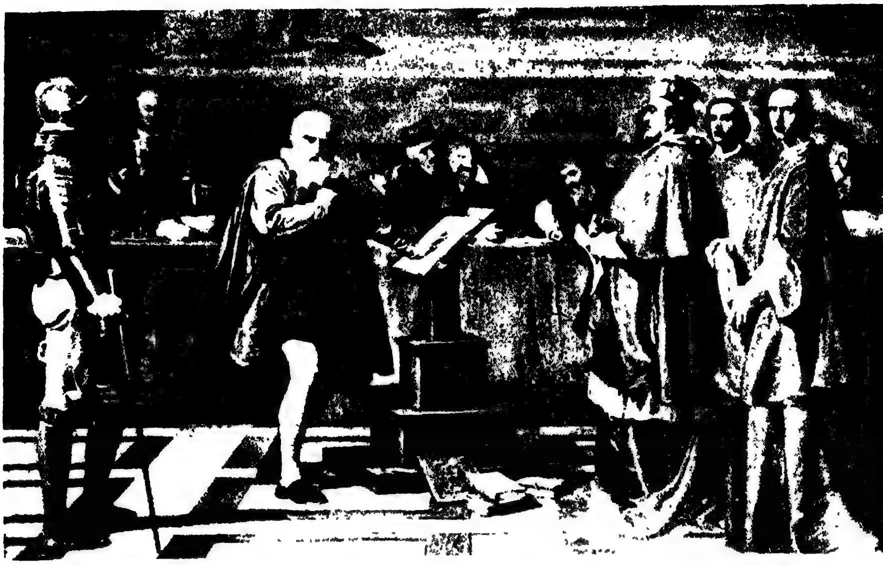


To the Chaldeans the earth was flat, with the sky resting like a dome on the surrounding wall. Inside the wall was a ditch to hold the oceans. Four white horses—or as some thought, elephants—held this chamber on their backs, and they in turn stood upon a turtle. But what the turtle stood on, no one seemed to know.



Below is Atlas, the unhappy god who held up the world of the Greeks. They were a kindly people, so in their myth they had him finally turned to stone.

At the left is pictured an early Greek notion by which the earth was regarded as a flat disk, with Mount Olympus in its center and the river Ocean flowing all around the outside of the disk.



The aged Galileo has just been forced to declare that he believes the earth to be the center of the universe, and to renounce his theory that the earth revolves around the sun. He was condemned by a tribunal of churchmen, because his theory was at that time believed to be against received Bible teaching.

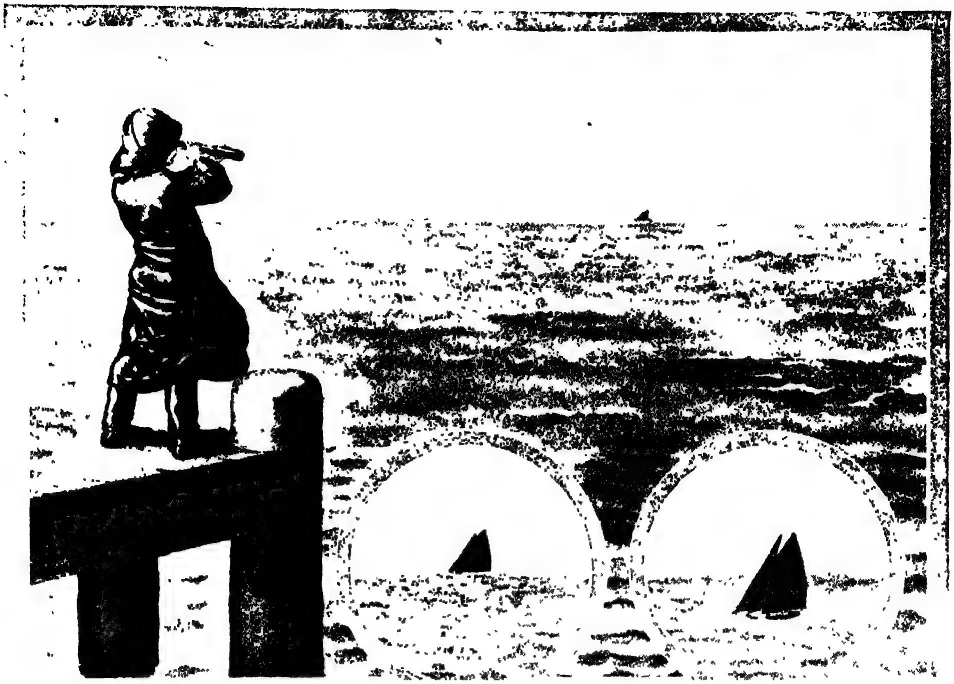
But an error cannot stand forever. A happier day was dawning, when people were not so much afraid to know the truth—and with it dawned the golden age of the science of the stars. Old childish beliefs could be cast away, and there were plenty of them that had to go. Our early forefathers, for instance, had thought the earth was flat—a mistake for which we surely can forgive them—and had invented various theories as to what held it up. Some of them were sure it was supported by four white elephants, who in turn stood on the back of a huge tortoise. An earthquake was easy to explain as a result of the natural restlessness of these unhappy beasts.

The God Who Held Up the World

Others thought the earth was carried on the shoulders of the god Atlas. To them the sky was a gigantic dome in which the stars were set; across it every day the sun was hauled in a blazing chariot by four fiery steeds. It is doubtful whether wise men shared these fanciful beliefs, but even they looked on the earth as the center of the universe. For a very skilful plan of things had been built up around that belief by an astronomer named Ptolemy (tŏl'ĕ-mĭ), who lived in Egypt in the second century after Christ. It is called the Ptolemaic (tŏl'ĕ-mā'ĭk) astronomy, and it reigned some fifteen centuries, until the ideas of Copernicus overthrew it. It was a very clever way of accounting for the movements of all the bodies in the universe, but unfortunately its starting point was wrong.

What Is the Universe?

Perhaps we should explain just what we mean when we speak of the universe. It is the term we use when we wish to speak of the sum of all existing things—of all creation, whether here beside us or as far away as thought can travel. It extends in every direction for countless billions of miles. Our little earth, which men once took to be the center of it, is merely one of the uncounted millions of bodies in it—and a small one, at that! We cannot be surprised that men of old made the mistake. The earth looks very large to us—much larger than the other heavenly bodies. How could our ancestors, long before there was



Every time a ship rises above the horizon it proves anew that the earth is round. For there could be no other explanation of the fact that the masts come in sight long before we see the hull.

a telescope, suspect that the sun was a million times as big as the earth, and that some of the stars were far larger still? Even to-day we can hardly realize that in comparison with the whole universe our earth is but a speck—a grain of sand!

The real science of astronomy begins at the point where men stopped listening to myths or guessing at explanations, and simply tried to learn the facts. An ancient Greek, Pythagoras (pĭ-thăg′ō-răs), seems to have known well enough that the earth is round, and Aristotle (ăr′ĭs-tŏt′'l), another famous Greek philosopher, knew it still better. The really wise men were convinced of it from that time on, but it was over eighteen centuries before the fact was commonly accepted—when Columbus had crossed the ocean and Magellan had sailed round the world.

It was Nicholas Copernicus (1473–1543), a Polish astronomer, who developed the notion first stated by a Greek named Aristarchus (ăr′ĭs-tar′kŭs) in the third century B.C.—that the earth is not the center of the universe, but merely one of several planets that circle round the sun; and it was a German named Johannes Kepler (1571–1630), who had the honor of discovering certain of the laws of motion which guide these planets in their courses.

Galileo (găl′ĭ-lē′ō), an Italian, became famous for all time when in 1610 he perfected the telescope—which had been invented by a Dutch optician, Lippershey, a few years earlier—and wrote a book to tell what he had seen through it.

After that it was not long before Sir Isaac Newton (1642–1727), an English mathematician, showed that the earth and all the other heavenly bodies are held to their courses by the force we know as gravitation (grăv′ĭ-tā′shŭn). These four men were the giants of astronomy.

Reading Unit No. 2

THE WHIRLING FAMILY OF THE SUN

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is meant by the solar system? 1–105
What is a planet? 1–105
What is a star? 1–105
How do planets get the light which makes it possible for us to see them? 1–105
How does the moon get its light? 1–105-6
What are the relative sizes of the different planets? 1–106
How far away is the sun? 1–106
Who was Kepler? 1–106

Things to Think About

If the planets had remained exactly like the sun, what would have happened to life on the earth?
Why does the length of a day differ on the different planets?
Why do the different planets have years of different lengths?
Why does a planet always follow its orbit?

Picture Hunt

Why are astronomical observatories built on mountain tops? 1–105
What are the planetoids? 1–106

Related Material

What optical instrument is used to determine the composition of heavenly bodies? 1–187
What part does centrifugal force play in the solar system? 1–311
Who was the first to tell the world that the earth moved about the sun? 13–394
What difficulties did Galileo encounter as a result of telling the world about his discoveries? 1–100, 102-3, 294, 13–397-98
What is the principle of the astronomical telescope? 1–185, 188, 189, 13–401, 403-4
Who were the astronomers of Greece? 1–103, 113, 169-70, 177, 5–160, 172, 13–2
What were some Greek and Roman myths concerning the constellations? 1–178, 14–425-32

Leisure-time Activities

PROJECT NO. 1: Make a chart of the solar system, 1–105-6
PROJECT NO. 2: Make a small model of a planetarium from clay or plaster, 1–105-6.

Summary Statement

The family of the sun consists of nine planets, with their satellites, all moving along regular orbits around the sun. Some of the planets have satellites of their own.

Photo by Lick Observatory

After James Lick, a California miner, had cast about for the best monument to leave to his name, he finally decided upon the great observatory above. It was built on the top of Mt. Hamilton, in California, and the body of its founder rests beneath the base of the great telescope. High above the clouds and the dust-laden air of the lowlands, the Lick Observatory gives the astronomers at the University of California, of which it is a part, a chance to study the heavens under the most favorable conditions.

The WHIRLING FAMILY *of the* SUN

How His Nine Children Race around Him about a Thousand Times Faster than an Airplane

THE early astronomers believed the earth was much the largest body in the universe. This was a natural mistake, for the earth was close at hand and there was no way of finding out the size of suns that were millions of miles away. In order to avoid the same error, let us fly in imagination to a point where we can get a bird's-eye view of our sun and its circle of planets and see them all in their true proportions.

What a surprise! When we arrive at our destination, we find that the earth has left the sky. No, no—not quite! A little dot of light is still there in the distance—showing the true proportion of our Mother Earth to the great sun, which from this point is by far the largest body in the heavens.

But what are those eight other "stars" which, like the earth, are dashing round the sun at different rates of speed? They look a bit like little marbles all rolling round on separate race tracks, one track inside another. These eight "stars" are the sister planets of the earth. Together with the earth, and with the sun, moon, asteroids (ăs′tẽr-oid), comets, and meteors, they form our solar (sō′lår) system, which takes its name from "sol," the Latin word for "sun"—because the sun is the center around which the other bodies revolve.

We must not make the mistake of thinking that the nine planets are really stars. Stars are very hot and bright, like the sun; and they do not move about as planets do. In a word, they are distant suns, more or less like our own. Planets, on the other hand, do not shine with their own light—they merely reflect the light of the sun. From the imaginary point in space on which we are standing, old Mother Earth seems to shine like a star; but she is only

doing what the moon does—she is reflecting sunlight.

The word "planet" has a pretty history. Early Greek astronomers did not know that the sun had a whole family of worlds, of which their own world was a member. But they had noticed that, while most of the stars kept to a fixed place in the pattern of the skies, there were just a few that roamed about, free to pursue each one its own course. So they called these roaming bodies "planets," which in the Greek means "wanderers."

The planets have been given names, which we shall list in the order of their distance from the sun, beginning with the little fellow that is nearest: Mercury, Venus, the Earth, and Mars—the four small worlds known as the inner planets—and Jupiter, Saturn, Uranus (ū′rȧ-nŭs), Neptune, and Pluto—the five outer planets. All of these travel around the sun in paths which the astronomers call orbits (ôr′bĭt), and are held to their courses by the mysterious force of gravitation (grăv′ĭ-tā′shŭn), of which we learned in the story of the earth.

It was Kepler who tracked the flying worlds and discovered the great laws by which each one finds its way. His remarkable discovery was one of the greatest of all time, for it enables an astronomer to tell just where any planet was, no matter how many thousands of years ago, and just where it will be, no matter how many thousands of years in the future. The three great laws that Kepler discovered sound simple enough: (1) that the path of every planet is an ellipse (ĕ-lĭps′), or flattened circle, with the sun a little to one side near the center of it, (2) that the speed of the planet as it dashes along varies after a certain fixed rule as the body reaches different parts of its orbit, and (3) that the length of time it takes a planet to circle round the sun has a definite relation to its distance from the sun. These are the laws that steer every scurrying body in the solar system; they are the stern rules by which the sun controls his restless family of children.

But perhaps you did not know that every world we have discovered is really a child of the sun and was once a part of the great ball of fire that warms us still and holds us all chained at a certain distance from him. For at a given distance from him the planets all whirl, each one at the end of the unseen cable that we call gravitation and each one at just the right speed to continue in the same path. We cannot escape; we cannot get back to our parent. Hung in the cold depth of space, each lonely world hurries on and on, year after year, age after age, and cannot even signal to his brothers and sisters in passing. We see the other worlds gleaming aloft at night—those that are near enough to be seen at all—and we turn around once every day to receive the glowing kiss of our parent sun. But on and on we must voyage, whirling and circling without ever jolt or jar; speeding indeed so smoothly that we cannot tell we are moving.

So far as anyone knows, this must keep up forever and ever—or at least for so many millions of years that man cannot stay on the earth to count them. Our race is but an incident in the life of the universe.

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Diameter Given in Miles	3,000	7,700	7,900	[illegible]	88,000	72,000	32,000	31,000	Unknown
Circumference Given in Miles	[illegible]	24,000	25,000	13,000	275,000	220,000	100,000	97,000	Unknown
Distance from Sun Given in Miles	36 Million	67 1/5 Million	93 Million	141½ Million	483¼ Million	886 Million	[illegible] Million	2791¼ Million	3,671.3 Million
Length of Year	88 da	224 [illegible] da	365¼ da	1 yr 321 [illegible] da	11 yrs 314 [illegible] da	29 yrs 167 [illegible] da	84 yrs [illegible] da	164 yrs 282¾ da	248 yrs 146 da
Length of Day Given in Hours and Minutes	Same as Year	Same as Year	23 hrs 56 min	24 hrs 37 min	9 hrs 55 min	10 hrs 14 min	Unknown	Unknown	Unknown
Number of Satellites	None	None	1	2	9	9	[illegible]	1	Unknown
Distance from the Earth	57 Million	26 Million	...	48½ Million	390¼ Million	793 Million	[illegible] Million	2698½ Million	3,578.1 Million

The above figures are approximate

Reading Unit No. 3

HEAT AND LIGHT FOR NINE WORLDS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the state of matter on the sun? 1 109

Which common earth substances have not been found on the sun? 1 109

How far away is the sun? 1-109, 115

How do astronomers study the sun? 1 109-10

What is the sun's surface temperature? 1 109

How large is the sun? 1 110

What do all fires on the earth need in order to burn? 1-113

What is the source of the sun's heat? 1-113

Things to Think About

How does the sun move?

Why do the seasons change?

What part of the sun's energy is available to us?

How do sun spots affect the earth?

Picture Hunt

What causes an eclipse of the sun? 1-108

Why do we have night and day? 1 118

Related Material

What were some ancient beliefs about eclipses? 5 160

How can energy be obtained directly from the sun? 1 348-50

How may a study of the sun help us to forecast the weather? 1 266

How does the sun provide our food supply? 2-366

What determines color? 1 419, 438

Why does our plant life depend upon the sun? 2-43, 50, 194, 223

Practical Applications

How may a study of the sun help us in long-range weather forecasting? 1-266

How may a person use the sun's energy to light a fire? 1 115

What do sun spots tell us about the sun? 1-112, 114, 116, 117

How may man some day be able to get his supply of electricity directly from the sun? 1-113

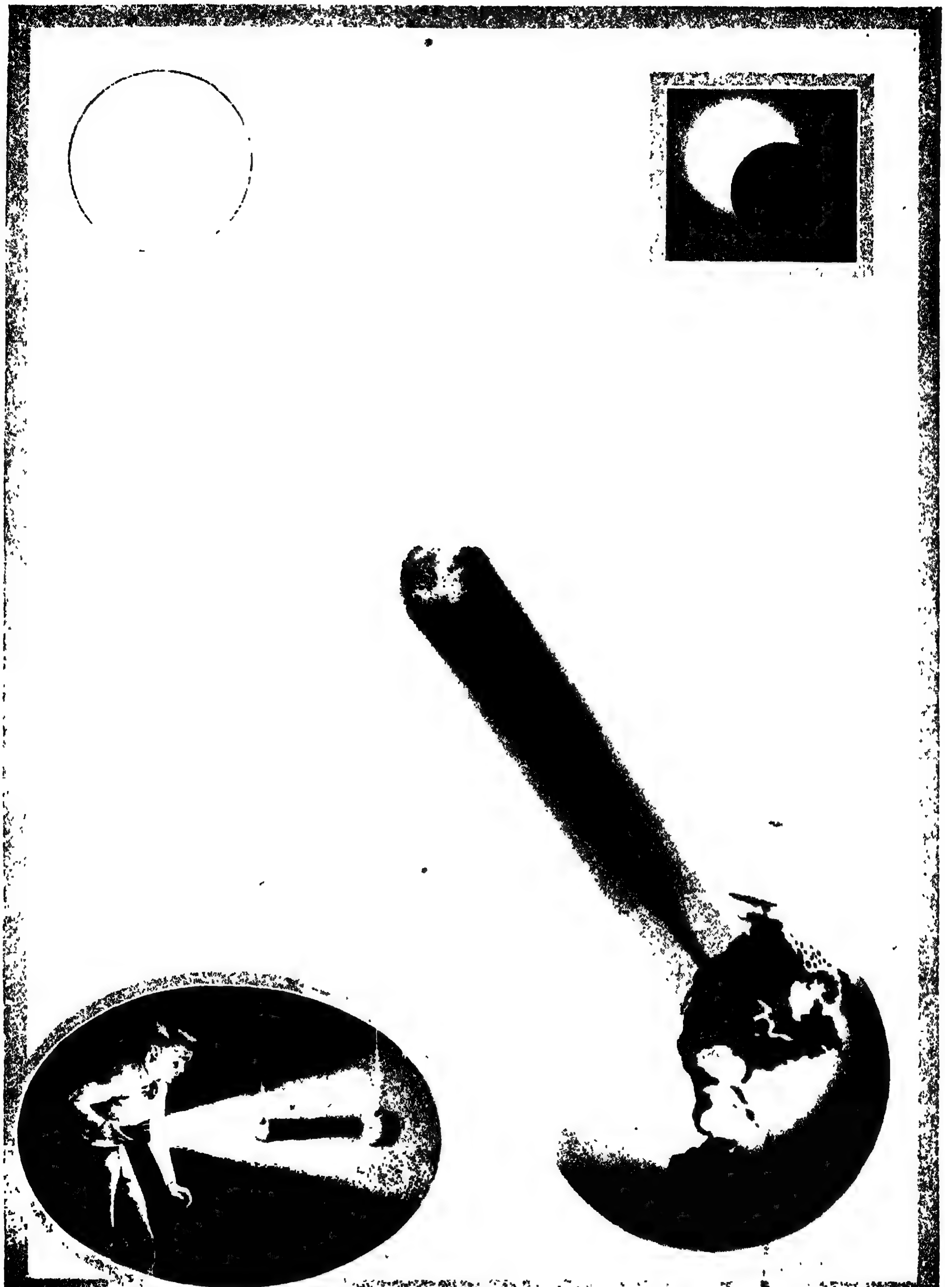
Leisure-time Activities

PROJECT NO. 1: Make a model eclipse of the sun. 1-108.

PROJECT NO. 2: Learn how to show the cause of day and night. 1-118.

Summary Statement

The sun provides the planets with heat and light. Life on the earth depends almost entirely upon the sun's supply of energy.



Occasionally the moon comes squarely between the earth and sun for a moment, and looks like a black disk against the sun. If only part of the sun is blotted out, we have a partial eclipse, shown in the square inset. But if the moon is in a position to blot out the whole sun, we have a total eclipse. Then the moon's black shadow traces a long dark line on the spinning earth, as shown above. The boy in the oval is illustrating an eclipse of the sun with a large and small apple for the earth and moon, and a flashlight for the sun.

Aurora, goddess of dawn, has thrown open the purple portals of the east and is strewing the way of the sun god with her roses. The fiery steeds have just been harnessed to the chariot by the Hours, who hand the reins to Apollo as he takes his place to drive his golden car across the sky and bring day to the earth once more. This famous picture was painted by Guido Reni, an Italian painter of the 17th century.

HEAT *and* LIGHT *for* NINE WORLDS

Once Supposed to Be a God, the Sun Is Now the Furnace and the Dynamo for All the Worlds We Know

THE men of old made up many a pretty tale to explain things which our modern scientists will toil for years to understand. They were pretty sure to look on any great force of nature as a god. Thus for the early Greeks the sun was Apollo, the most glorious of all the deities and the patron of medicine, music, poetry, and all the arts. Every day he drove his shining chariot across the heavens, from the gates of the dawn, flung open by the "rosy-fingered Aurora," to the western ocean, where a golden boat was waiting to bear him back to his palace in the east. On his faithfulness rested the welfare of man.

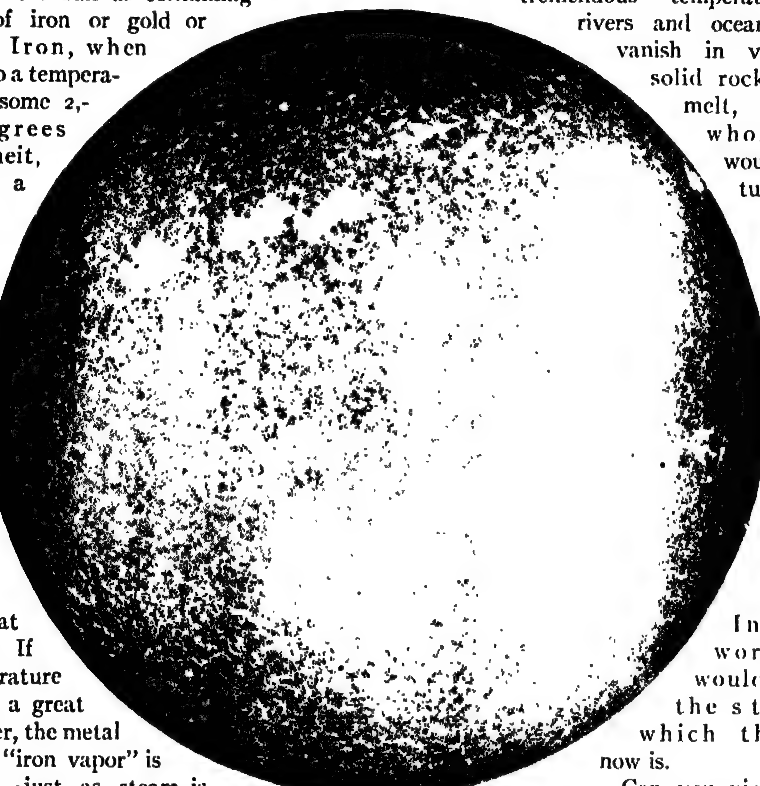
Now whether or not all the people believed this fantastic tale—and surely the wise ones thought of it merely as a good story—they certainly knew that all life depends upon sunlight. For this reason many peoples, such as the ancient Persians, worshiped the sun as the highest power in the universe. But they never dreamed that he is the center around which the earth travels or that he is much larger than the earth—and probably they never guessed what he is made of.

How should they? A ball of fire! But that does not tell us much. We are left still wondering what it is that burns. Unless you had read the story of how the earth was made and knew that we were once a part of the sun's glowing body, you would never suspect that earth and sun are composed of the very same materials. To be sure, our own familiar substances—iron and copper, nickel, silver, zinc, aluminum, and manganese (măng'gȧ-nēs')—are present in the sun only as gases, and not as the solids that we know; but that is only because they are so hot. Phosphorus (fŏs'fŏr-ŭs) and sulphur, gold and mercury have not been found there, but forty of the other substances that chemists know have been discovered.

It sounds like magic. How can we tell what goes to form a body 93,000,000 miles away? But modern science can work these miracles. No one has ever made a journey to the sun, but a knowing little instrument called a spectroscope (spĕk'trō-skōp) tells us a great deal about what the sun contains. The spectroscope is handmaid to the telescope. It takes a ray of sunlight and separates it into all its various parts—for

every substance, when heated to the temperature existing in the sun, gives off its own especial kind of light.

All this is possible because the sun is so very hot. All the substances in it exist in the form of gases, hotter than any temperature man can create. So we must not think of the sun as containing lumps of iron or gold or silver. Iron, when heated to a temperature of some 2,700 degrees Fahrenheit, turns to a liquid that will pour. If its temperature is raised a great deal higher, the metal boils and "iron vapor" is given off—just as steam is given off from boiling water. In this state the iron may be called a gas. First it was solid, then liquid, then a gas—and it is as gas that iron and all other substances exist in the sun. For the temperature is around 11,000 degrees Fahrenheit on the surface of the sun, and immensely hotter at the center.



This is a picture of the sun, taken through the great 40-inch telescope at the Yerkes Observatory, in Wisconsin. The small black dots are "sun spots" - great whirlpools on the sun's surface—and the bright spots are very brilliant patches of calcium vapor.

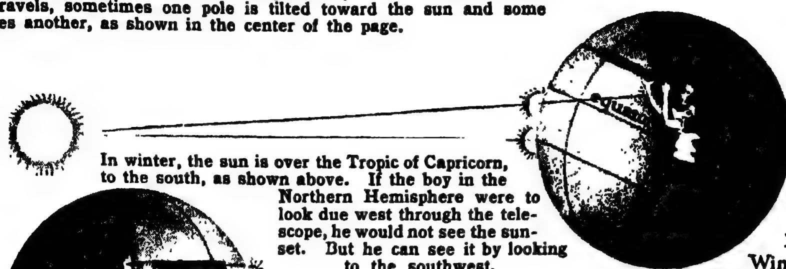
How Big Is the Sun?

All this makes the opinion of one of the older astronomers rather funny. He regarded the sun as "a solid globe girt round with cloud and fire," and believed that it was "richly stored with inhabitants, dwelling amid romantic scenery and luxuriant vegetation." One wonders just what people would be like if they could live in such a furnace.

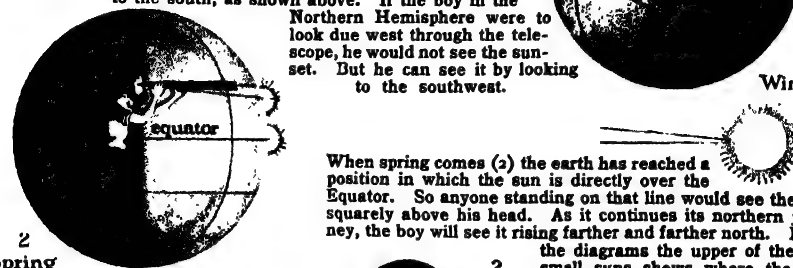
As a matter of fact, if our own solid earth were heated in some big oven to such a tremendous temperature, its rivers and oceans would vanish in vapor, its solid rocks would melt, and its whole bulk would finally turn to gas. In other words, it would be in the state in which the sun now is.

Can you picture the size of the sun? Probably no one can. We have no trouble in imagining the size of a pinhead, a football, or even a mountain; but we cannot imagine the size of the earth as a whole—and even the earth is small when compared with the vast bulk of the sun. The earth has a diameter of 7,918 miles, while the sun has one of 865,000 miles; and this means that the sun is more than a million times larger than the earth. If you were to take a chunk as big as the earth out of the sun every day, you would need 3,600 years to finish the job. So you can see that even if the earth were

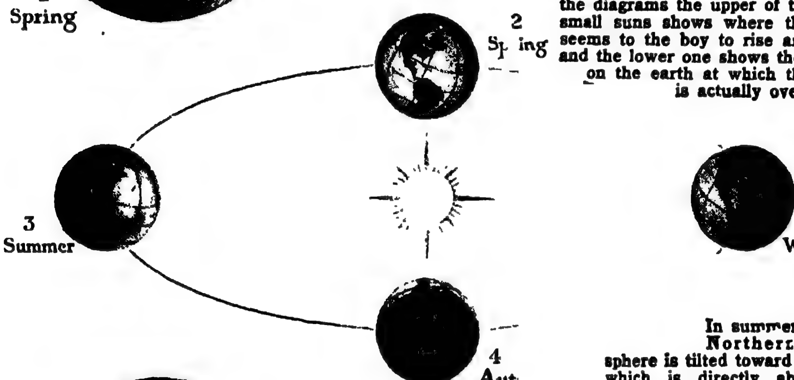
The pictures below will show you why the sun sets so far north in summer and so far south in winter. The earth, as you know, does not stand with its axis at right angles to the plane in which it circles round the sun. It is always tilted, with the result that as it travels, sometimes one pole is tilted toward the sun and some times another, as shown in the center of the page.



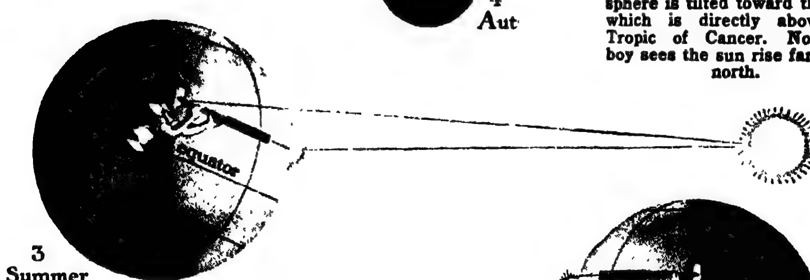
In winter, the sun is over the Tropic of Capricorn, to the south, as shown above. If the boy in the Northern Hemisphere were to look due west through the telescope, he would not see the sunset. But he can see it by looking to the southwest.

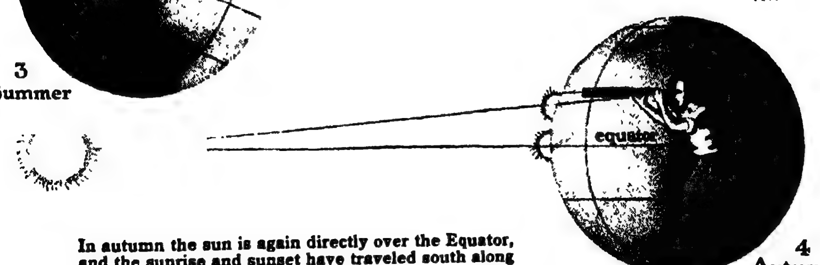


When spring comes (2) the earth has reached a position in which the sun is directly over the Equator. So anyone standing on that line would see the sun squarely above his head. As it continues its northern journey, the boy will see it rising farther and farther north. In all the diagrams the upper of the two small suns shows where the sun seems to the boy to rise and set, and the lower one shows the point on the earth at which the sun is actually overhead.



In summer (3) the Northern Hemisphere is tilted toward the sun, which is directly above the Tropic of Cancer. Now our boy sees the sun rise far to the north.



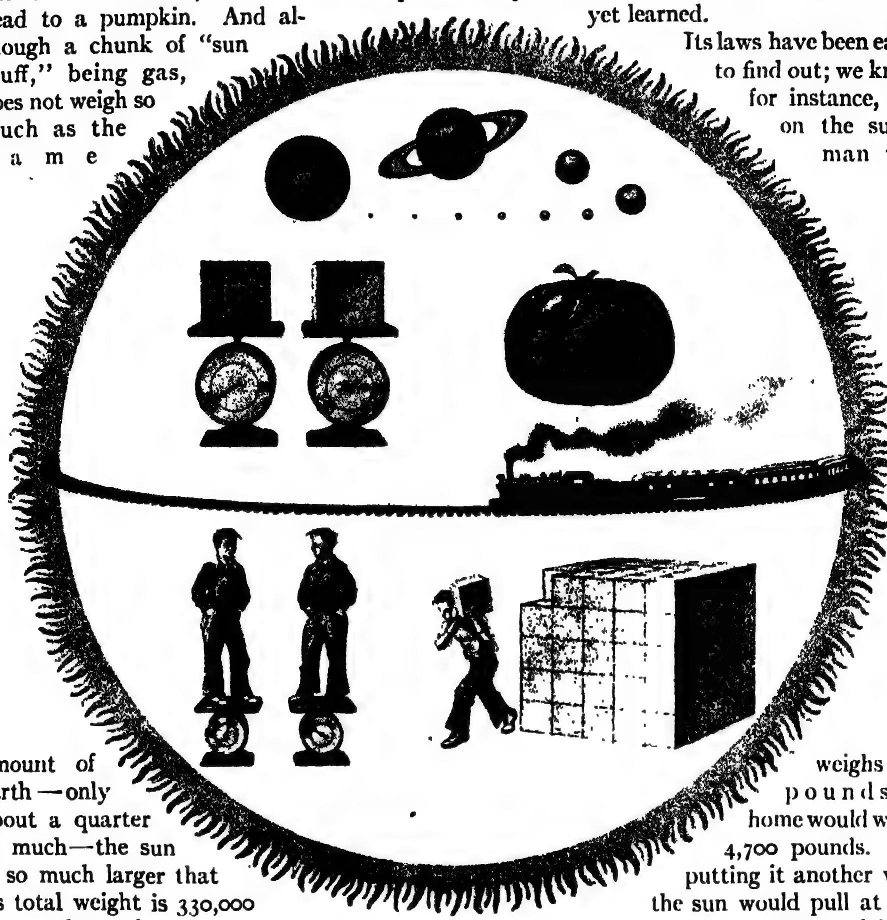


In autumn the sun is again directly over the Equator, and the sunrise and sunset have traveled south along the horizon.

a ball of fire like the sun, it would be barely visible from the sun's surface. In comparison with the sun, it is about like a pinhead to a pumpkin. And although a chunk of "sun stuff," being gas, does not weigh so much as the same amount of earth—only about a quarter as much—the sun is so much larger that its total weight is 330,000 times that of the earth. Yet even our baby earth weighs six sextillion — 6,000,000,000,000,000,000,000—tons!

It is his tremendous size which makes the sun the center around which all the planets wheel. That is the secret of the force with which he holds them near him. We call it gravitation (grăv'ĭ-tā'shŭn), but that is just a useful name, describing how it acts. What the force really is and how it pulls, we have never yet learned.

Its laws have been easier to find out; we know, for instance, that on the sun a man who weighs 168 pounds at home would weigh 4,700 pounds. Or, putting it another way, the sun would pull at him as powerfully as the earth would pull upon 4,700 pounds. Imagine the strength he would require to lift an arm or take a step. He would be rooted to the selfsame spot for all eternity.



This giant disk is the sun, with flames darting out from it on every side. Upon its surface we have drawn various pictures to help give you an idea of what the sun is really like. At the top is the sun with its family of nine planets, all of them drawn to scale with relation to the sun. Below them are two scales, the one at the left loaded with a cubic foot of earth stuff, and the other with a cubic foot of sun stuff. You will notice that the weight of the gaseous sun stuff is only 88 pounds, while the earth stuff weighs nearly four times as much. Beside the scales is a pumpkin. Let us suppose that a pin is lying near the pumpkin. The head of that pin bears about the same relation to the pumpkin in size as the earth bears to the sun. If the express train that you see is traveling at the rate of forty miles an hour, it will take 72 years, 3 months, and 19 days to travel round the sun; and if the boy below at the right could take a piece the size of the earth out of the sun every day, it would take him 3,600 years to move the whole of the sun. At the lower left hand are two pictures of the same boy. In the one at the left he is standing on the earth, and weighs 100 pounds, but the other shows him standing on the sun, where he weighs 2,800 pounds.

It may be interesting to add that the same well-developed man would weigh only twenty-eight pounds on the moon. For the

moon is so much smaller than the earth that it can pull with only one-sixth of the force. Our traveled gentleman would feel almost as light as air!

Will the Sun Ever Go Out?

Times are always changing. An ancient philosopher named Anaxagoras (ăn′ăk-săg′-ô-răs), who was born five hundred years before Christ, was put in prison for saying that the sun was a huge ball of fire, possibly as large as his native country of Greece! Surely, you will say, it is ridiculous to send a man to prison for such a harmless statement. But the statement did not seem so "harmless" to the Greeks—it interfered with their religious faith, for they had worshiped the sun as a god. And they could think of no answer to the argument except to throw the wise man into prison.

The disappointing thing about a bonfire is that it lasts so short a time. No matter how big we make it, it will soon burn out. Now if the sun were aflame in just the same way as a bonfire, it too would soon die down. Because it is so large, it would last a very long time in comparison, but in about five thousand years its glowing ball would have burned up entirely. We can be sure, therefore, that the sun burns with quite another kind of fire, for its rays must have shone upon the giant forests that went to lay down our coal fields millions of years ago.

How the Sun Gets Its Heat

The kind of fire we make will not burn without air. Since there is no air around the sun, it is clear that its terrific heat must come from some other kind of "fire" than that which burns inside our stoves and furnaces.

Accordingly, we believe that the heat in the sun results in part from the amazing fact that gases, if they shrink, grow very hot. On account of its own gravity, the sun's diameter is constantly shrinking, for the mass at the center is constantly pulling in the surface. The seething gases of which it is made up are therefore kept at a tremendous temperature.

But if its shrinking gases help to keep it hot, an even mightier force raises its heat to unimaginable heights. For the sun is nothing more nor less than a great dynamo of electricity. Changes constantly taking place in the substances of which the sun is made free such mighty forces as men in bygone days could never dream of. They warm us and light us and give us pulsing life. Man has only just begun to find out what they are, but when he learns to harness them, we shall have marvels to take our breath away.

Why the Sun Does Not Go Out

This is the reason why the sun has never burned itself out and why it does not seem to grow noticeably cooler. Its heat will last for millions upon millions of years—far longer than the human race can hope to stay on the earth. People who live a hundred thousand years from now will find its friendly warmth not one whit colder and its light not one whit dimmer than they are to-day. Recent discoveries as to the nature of atoms—the tiny particles of which all matter is composed—show that the sun's heat can be maintained for indefinite ages. The enormous quantities of radium and like substances which the sun contains will continue to give off heat and light for a longer time than man can measure.

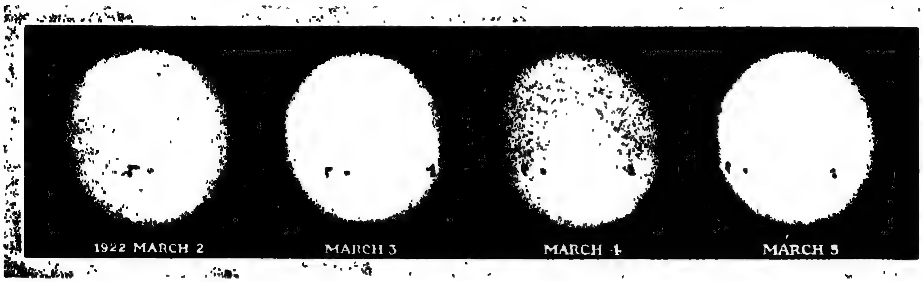
We have already seen that the sun is not solid like the earth, but is a ball of hot gases. The great magnetic cloud of which the sun and earth and all the other planets were once parts was whirling rapidly before it was broken up, and its parts all spin to this day, because there is nothing to stop them.

Does the Sun Move?

It would be very hard to find out the speed with which the sun is turning if it were not for certain spots that mar its shiny disk By careful watching we can see them move slowly across its face from east to west. Then they disappear, and are not visible again until they show once more upon the eastern side. On the equator of the sun it seems to take them twenty-five days to get around. But the farther they are from the equator, or the nearer to the poles, the longer it takes them, curiously

enough, to turn. Half way between pole and equator they take 27½ days to rotate.

But in addition to its spinning the sun has another motion. It is constantly drifting through space at a rate of twelve miles a second, or a million miles a day; and as it drifts it carries with it—in the powerful grasp of gravitation—all of its planets and their attendant bodies, the earth and moon included.



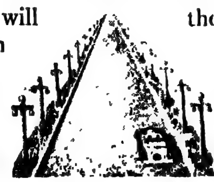
Here are four pictures of the sun, taken on four successive days. The black dots are sun spots, and their movement from right to left shows that the sun is constantly revolving in that direction.

How We Know the Stars Move

Astronomers have made out the general direction of this majestic movement and its rate of speed, but they do not yet know just what kind of path the sun is tracing. They only know that in a hundred years it has not swerved noticeably from a straight line.

Let us suppose that some evening you start to drive down a long straight street. Its lights—two long even rows—stretch out before you till, far in the distance, they seem almost to meet; and yet, no matter how far on you go, you find that they are always the same distance apart. When you have traveled to the very end, you will will discover that at the point from which you started the lights now look as close together as they had first seemed to be at the end where you have just arrived. And when you are halfway down the street, the rows will seem to run together both ahead of you and behind you.

As you look behind you from an automobile that is moving swiftly down a long street, you see the lights at the end of the street coming nearer and nearer together. It is by this "law of perspective" that we can prove that the sun and its planets are all moving along together through space. When distant stars come nearer and nearer together, we know that it must be because we are leaving them farther and farther behind.



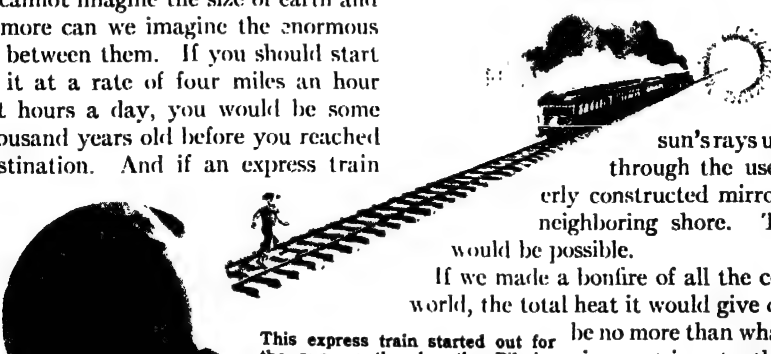
It was Sir William Herschel, a great German-English astronomer, who first saw that the appearance we have just described might explain various facts in the heavens. In 1783 he noticed that certain stars in the northern sky appeared to be moving farther apart, but that others in the southern sky appeared to be coming closer together. He concluded that the reason for the apparent change must be that we are moving toward the stars that are opening out and away from those that are closing up. But if we were moving thus, our sun and all its other whirling children must be so moving too, for all are held together inescapably by the sun's gigantic arms—that is to say, by gravitation. Accordingly, Herschel was able to state that our sun is drifting toward the constellation (kŏn′stĕ-lā′shŭn), or group of stars, known as "Hercules" (hûr′kū-lēz). The discovery of this drift and of its rate is one of the marvels of modern astronomy.

And not only have we learned that our own sun is drifting. All the suns—or stars—in the great universe are traveling also, at varying rates of speed, though on account of their tremendous distances from us they seem to move very slowly. It is only because each one swings along at his own rate and in his own direction that we find it possible to observe their motion. If they were all moving at the same rate and in the same direction, we should have no way of telling that they moved at all, for there would then be no point from which to observe their passing.

But the problem of mapping out their courses is tremendously puzzling. Imagine twelve rowboats out at sea, away from sight of land, and all moving at different rates of speed in different directions; and suppose the boat that you are in is moving too. You can see at once how hard it would be to find out the speed of all the various boats. Yet that would be as nothing to the problem of calculating the speed and pathways of a multitude of stars trillions of miles away.

How Far Away Is the Sun?

If we cannot imagine the size of earth and sun, no more can we imagine the enormous distance between them. If you should start to walk it at a rate of four miles an hour for eight hours a day, you would be some eight thousand years old before you reached your destination. And if an express train had set out in 1620, on the day the Pilgrims started for America, it would only recently have reached the sun. For ninety-three millions miles is a long way, and that is the distance to the sun. A ray of light travels 186,300 miles a second, and yet it takes eight minutes and twenty seconds for a sunbeam to travel to the earth. If light from our own familiar sun takes such a time to reach us, what must be the time required for a ray from the far-distant stars, trillions and trillions of miles away?



This express train started out for the sun on the day the Pilgrim Fathers set sail from Plymouth to come to America—and it reached its destination only a little while ago. The boy, if he lives, will be an old, old man before he reaches the sun; for if he goes at the rate of four miles an hour for eight hours a day, he will be eight thousand years old when he finishes his journey.

The sun is constantly pouring forth heat at a rate that our little imaginations find impossible to grasp. Our earth receives but a very tiny fraction of the total output—about $\frac{1}{2,200,000,000}$ of it—for the sun lavishes its warmth through all space. The sun is so hot that if we could catch and store all the heat sent out by an area on its surface no bigger than a town lot, there would be enough to get up steam in the boilers of all the factories in a large city and to keep them going for countless thousands of years.

You have doubtless experimented with a "burning glass." An ordinary watch crystal will do. If you hold it with the hollow side down, you can gather together all the rays that fall on the crystal and focus them on a piece of paper until it is so hot that it will take fire. We are told that a famous Greek philosopher named Archimedes (är′kĭ-mē′dēz), in the third century before Christ set fire to Roman warships by directing the sun's rays upon them through the use of cleverly constructed mirrors on the neighboring shore. The thing would be possible.

If we made a bonfire of all the coal in the world, the total heat it would give out would be no more than what the sun gives out in a tenth of a second. There is no fire on earth to which the sun's heat can be compared. And yet, in spite of all its generosity, the sun does not seem to cool off. It has been warming space for millions of years and as yet we cannot feel that its heat is decreasing at all.

Spots on the Sun's Bright Face

To the ancient Greeks the sun's bright face was the most spotless thing in nature. The telescope told a different tale, but long before its coming the Chinese had discovered that the golden disk was spotted; in fact, they knew it some two hundred years after the birth of Christ.

What are the spots? They look like very dark blue patches, and represent gigantic holes in the sun's white surface. But this does not mean that the sun is dark inside. The holes are thought to be great whirlpools caused by huge magnetic storms. They look dark only because they are less bright

than the area around them. If you could place a brilliant arc lamp against the surface of the sun, it too would look quite black—a good deal darker than the spots. So the sun spots are not really black, but only seem to be.

These spots are of tremendous size. The smallest is five hundred miles across, and some are so large that the earth could be dropped into them. In fact, the giant planet Jupiter might be slipped into certain of these cavities without making a ripple in their margins.

There is a story—probably untrue—that Archimedes, an ancient Greek philosopher, succeeded in setting fire to an enemy fleet merely by reflecting upon it the rays of the sun concentrated in a huge mirror.

How Sun Spots Affect the Earth

There are not many days when the sun's face is quite clean. Nearly always there are a few patches on it, and from time to time it breaks out much more violently. Occasionally the spots are very large. The period of most numerous eruptions—what is called the maxima (măk′sĭ-mȧ), or "greatest number"—comes once in eleven years, with the period of fewest eruptions—or minima (mĭn′ĭ-mȧ)—halfway between. We say they complete a "cycle"—or circle—every eleven years.

The largest spots often send forth great flames called "prominences"—sometimes to a height of 300,000 miles. These are most numerous during the period when there are a great many sun spots. Lucky for our earth and all the other planets that they are at a safe distance!

But even though we are 93,000,000 miles away, those "stormy" seasons on the sun affect us here on earth. They upset our electrical instruments and are thought, by some observers, to influence the weather. The northern lights—called the "aurora borealis" (ô-rō′rȧ bō′rē-ā′lĭs)—are much more frequent and more brilliant at such times. All this is easy to believe when we know that earth and sun are both huge magnets and that the earth is constantly receiving electrical discharges from the sun.

One of the most dramatic events in nature is a total eclipse (ē-klĭps′)—or "blotting out"—of the sun. Few people had been lucky enough to see one until recently. But in 1925 the spectacle had a greater audience than it had ever had before in the history of the world, for it was visible over a densely peopled area in the northeastern part of the United States. There people turned out by millions on a clear winter morning to see the sun swallowed up by what our earliest forefathers, in their surprise and fear, believed to be an enormous dragon.

But we know now that the terrific creature that "eats up" the sun is nothing more nor less than our old friend the moon. It is all quite simple—as are so many things when once one knows the explanation. Because the moon is constantly circling round the earth, it sometimes comes between the earth and the sun and hides the sun, just as a person passing between you and a lighted lamp may hide the light. This does not happen very often, for the orbits (ôr'bĭt)—or race courses—of the moon around the earth and of the earth around the sun do not lie on the same level, or, as we say, "in the same plane." The moon's is tilted slightly, so that only occasionally—always twice but never more than five times in a year—can it get in line between the earth and sun. Even then it hides only a part of the sun's face, as a rule, with the result that we have an event which most of us have seen—a partial (pär'shăl) eclipse of the sun.

But twice in every three years the moon covers up the sun entirely. This is not because it is larger than the sun; it is a mere speck in comparison. But just as a penny held close to the eye will hide a distant hill, so the little moon, since it is so much nearer to us, can blot out the huge but distant sun. When this happens, the moon's great cone-shaped shadow rests for a brief space upon a portion of the earth and plunges it in darkness.

Even modern man feels a certain awe at seeing the sun wiped out. Gradually, as the moon's black disk—black because the sun is behind it and the moon's face can receive no light—travels across the sun, the light of day dies out. A strange, ghostly twilight falls, with weird ashen shadows and flickering bands of light playing on everything. One by one the stars come out; birds go to rest. Finally the moon slips into place upon the surface of the sun and night has come, except that round the moon there gleams a pearly ring or "crown" of light known as the sun's "corona" (kô-rō'nȧ).

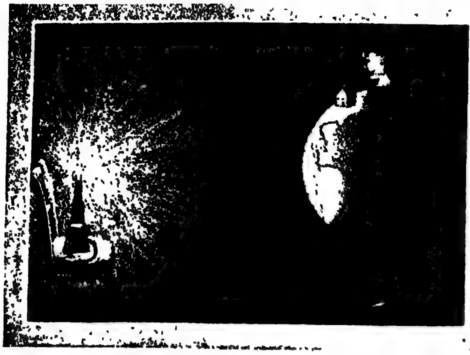
This is a view of one of the sun spots, taken through a giant telescope. You may have some idea of the size of that vast whirlpool when you see how the earth would look if it were dropped into the center of the hole.

For King Sun has a halo, or "crown." Astronomers cannot tell us what it really is, though some of them believe it to be due, in part at least, to the reflection from a great cloud of "dust" that floats around the sun.

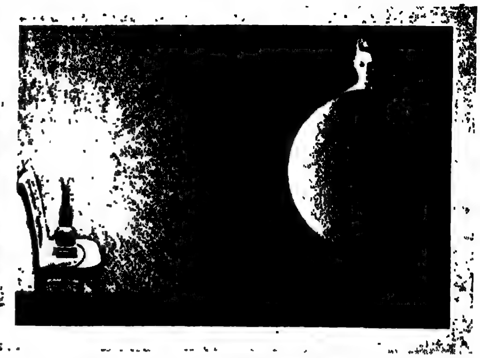
But where, you ask, could such dust come from, if the sun is made of gas? From countless small lumps of solid matter—stone and metal—with which all space is teeming. We call such bodies meteors (mē'tê-ŏr). Many millions of them are known to enter our atmosphere daily and thousands of millions must fall into the sun each day. It is only during a total eclipse, when the whole sun is hidden, that the corona can be seen. At all other times it is lost in the sun's dazzling glare—which is called the "photosphere," meaning the "sphere of light."

The Sun's Gigantic Flames

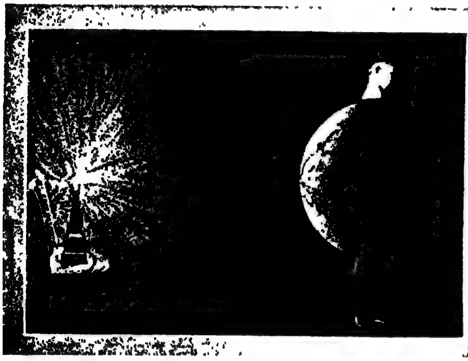
But during an eclipse the corona is not the only evidence that the sun is still alive. Out from behind the moon there shoot into space gigantic flames, the solar "promi-



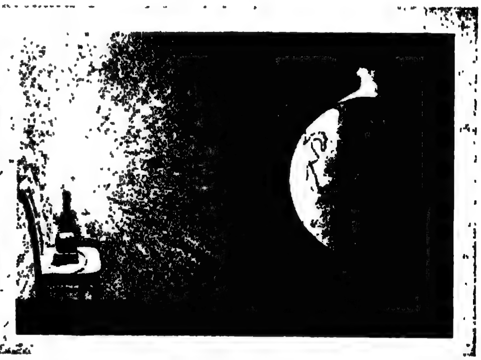
Let us suppose that the lamp in the picture above is the sun, and that the little house on the earth is your own home, in full sunlight at high noon.



Your house is now in partial shadow, for the earth has spun around a quarter of the way, and it is six o'clock at night. Evening is rapidly coming on.



Our boy has spun his earth halfway round, and your house is in pitch darkness, for it is midnight. Now China, on the other side of the earth, is having its day.



Six more hours have passed while our earth swings round, and the sun is rising at your house; that is, the lamp is just coming into view at that point.

nences" we have described above. Sometimes they are not visible to the naked eye, but the telescope always shows them as they burst forth from an enveloping cloud of gas known as the "chromosphere" (krō′mô-sfēr), or "color sphere." In fact, with an instrument called the spectroheliograph (spĕk′-trô-hē′lĭ-ô-gráf), the prominences may now be photographed at any time.

The impressive spectacle of the sun's death lasts, at most, but a few short minutes—usually three or four and never more than seven. As earth and moon swing by, a tiny rim of light appears again, thi. time at the moon's other edge, and the sun's life-giving warmth is once more restored to man. The early Chinese felt sure that they had themselves saved the sun by banging upon pans and kettles and so frightening the dragon away; and northern peoples believed that by making a tremendous noise they alarmed two hungry gray wolves that had been caught in the very act of eating up the sun.

A Great Event for Scientists

Though the event lasts so short a time, an eclipse is the occasion of tremendous preparation and of feverish activity while it lasts. Astronomers can forecast, thousands of years ahead, the precise times and places where eclipses will occur. Telescopes and many other scientific instruments are carried at great expense to the part of the globe where the eclipse is due, and groups of scientists make the journey to take the observations. It is a highly sporting expedition, for if the day is cloudy, all the time and effort go to waste. But if all goes well, science is richly rewarded.

Reading Unit
No. 4

THE ONLY CHILD OF MOTHER EARTH

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the source of the moon's light? 1-122, 123, 125

What is meant by centrifugal force? 1-122

Which planets have more than one moon? 1-122-23

What is believed to be the moon's origin? 1-122

Do we see all parts of the moon's surface? 1-123-24

What is meant by the eclipses of the moon? 1-125-26

Where and when does the moon rise? 1-127-28

Things to Think About

How may the moon have been born?

Why do we never see one side of the moon?

Why does the shape of the moon seem to change?

Why does the moon rise later each night?

Picture Hunt

Why is it possible to see the old and new moon at the same time? 1-127

When does an eclipse of the moon take place? 1-126

Related Material

How does the moon cause eclipses of the sun? 1-108, 117

What would a person see on a trip to the moon? 1-136, 299-301

How do some people try to forecast weather by studying the moon? 1-265

Which are the moons of other planets? 1-106, 12-279

What is meant by the eclipses of Jupiter's moons? 1-155

How are eclipses recorded? 1-188

Why was the moon worshiped in ancient times? 1-121

Practical Applications

What is the basis for the length of the month? 1-124-25

How well could we get along without the moon? 1-122

Leisure-time Activities

PROJECT NO. 1: With a lamp and ball, produce the phases of the moon as illustrated on 1-12

PROJECT NO. 2: Show why we see only one side of the moon, 1-129.

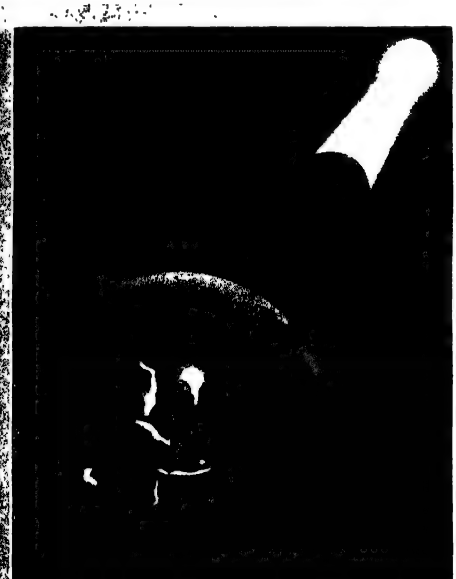
Summary Statement

The moon, which reflects light to us from the sun, accompanies the earth in the earth's movement about the sun and is believed to have come originally from the earth.

When earth, sun, and moon are in this position, we see only part of the moon—the crescent. The boy is holding the ball in the same relation to the light. His head is the earth, the ball is the moon only partly illuminated, and the lighted lamp is the sun.

Here the moon is on the opposite side of the earth from the sun, so we see the full moon; that is, the whole disk is in full light, just as the ball is. The boy's head does not here represent the earth, which at full moon is really between the sun and moon.

Now the moon has traveled round to the other side of the earth; she is on the wane, and once again only part of her disk is illuminated for us on earth.



When the moon is between the earth and sun, we cannot see her; the side toward us is in shadow, just as the side of the ball is. It is the dark of the moon.

When you gaze at the moon and her company of stars, does it ever occur to you that she is the very same moon that men have loved since time began? Our savage forefathers marveled at her; the people of Egypt and Babylon worshiped her; Greek maidens like the ones above took her as a type of their own purity; and Caesar, Plato, Moses, Jesus all felt the power of her beauty just as you and I do to-day.

The ONLY CHILD *of* MOTHER EARTH

Though She Has Been Dead for Ages, the Pale Moon Is Still the Most Beautiful Thing in All the Sky

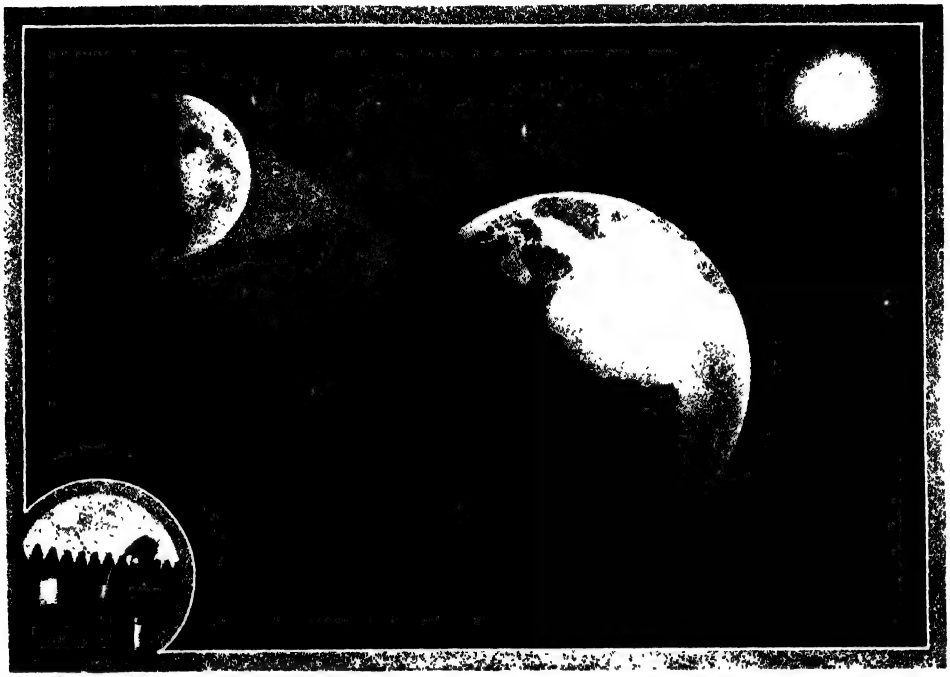
THE moon has always had a rather bad reputation—it is hard to tell just why; for she certainly is the most beautiful of all the bodies in the sky. "Oh, swear not by the moon, the inconstant moon," says the greatest of our poets; and in the gentle slur he is only echoing what countless other men have said.

Perhaps early men found her changing moods too mysterious; perhaps they stood in awe of her because she reigned at night; perhaps it was merely that her cold silver suffered beside the glowing gold of her brother, the sun.

For she was early thought of as his sister. Diana, she was called—the shy goddess of the hunt, who never fell in love, but with her group of maidens ranged the woodland, goddess of groves and fountains and guardian of mortals against disease and pestilence. Later, her worship turned to weird superstition. All sorts of magic charms were wrought in the dark of the moon, when the powers of evil were let loose; and heathen priests, such as the druids in England, observed the days when she was full with various horrid rites. It was by moonlight, too, that ghosts were said to walk. When she was at the full, her influence was friendly; but when she was on the wane—or growing smaller—she brought bad luck to men. Her power for good and evil was enormous; she influenced the weather, the growth of plants, and even the affairs of state. Over the weak-

witted she was thought to have a very bad influence; indeed, they took the name of their disease from her and were called lunatics from her Latin name of "luna."

Though the moon has always been an inspiration to the poets, her practical value, it must be confessed, is very slight. We could get along quite well without her. She gives no heat at all and all her light she borrows from the sun. In other words, moonlight is but reflected sunlight. We cannot tell for certain where she came from, but many astronomers (ăs-trŏn′ō-mẽr) believe that she is the earth's own child, once a part of our planet but hurled off while it was still molten.



The moon borrows all her light from the sun—for moonlight is only reflected sunlight, as you may see from this picture, in which the moon, in the upper left-hand corner, is sending to us on the earth light that she has just received from the sun. In other words, the moon acts just as the mirror acts in the hands of the boy in the inset. The bright patch on the fence is really light the mirror reflects from the sun.

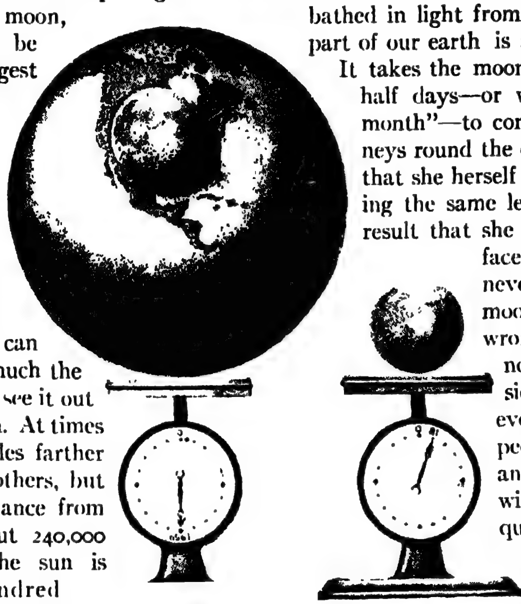
How the Moon May Have Been Born

The earth was whirling then at a terrific speed—some four times as fast as now. You have noticed that when you are on a merry-go-round, you have to lean toward the center to keep from being hurled off at the side; and the faster you go, the farther you must lean. This is the effect of what we call centrifugal (sĕn-trĭf′ū-găl) force; it is caused by the tendency that all moving objects have to keep on going in a straight line. You can readily see that, with the earth still soft and whirling so rapidly, it might have been easy for a piece of it to break away and dash off into space. Or, as scientists put it, centrifugal force could easily overcome the force of gravity (grăv′ĭ-tĭ)—the force that keeps the earth together and holds us on it even though it is whirling fast enough to send us hurtling into space at the rate of sixteen miles a minute.

You must know that our own planet is not the only one that has the dignity of having an attendant. Mars has two, Uranus four, and Jupiter has nine. In fact our own familiar moon is only one of twenty-seven that are known to be distributed among the various planets. There may be more. They

range in size from a little five-mile affair that dances attendance upon Mars to a gigantic servitor of Saturn that bears the name of Titan and is 3,550 miles in diameter, or nearly as large as the planet Mercury. Our own moon is by no means a pigmy. Her waist is 2,163 miles through—a quarter of the thickness of the earth.

It is always a bit surprising when one learns that the moon, which seems to be one of the largest bodies in the heavens, almost as big as the sun and vastly larger than the stars, is in reality the smallest of all the bodies that our naked eye can see. It is so much the nearest that we see it out of all proportion. At times it is 30,000 miles farther away than at others, but its average distance from us is only about 240,000 miles, while the sun is some four hundred times farther off and the stars immensely farther still. The powerful telescope on Mount Palomar makes the moon seem only a few miles away. So astronomers have learned a great deal about her. We have better maps of her bright face than of many parts of Africa or of our polar regions.



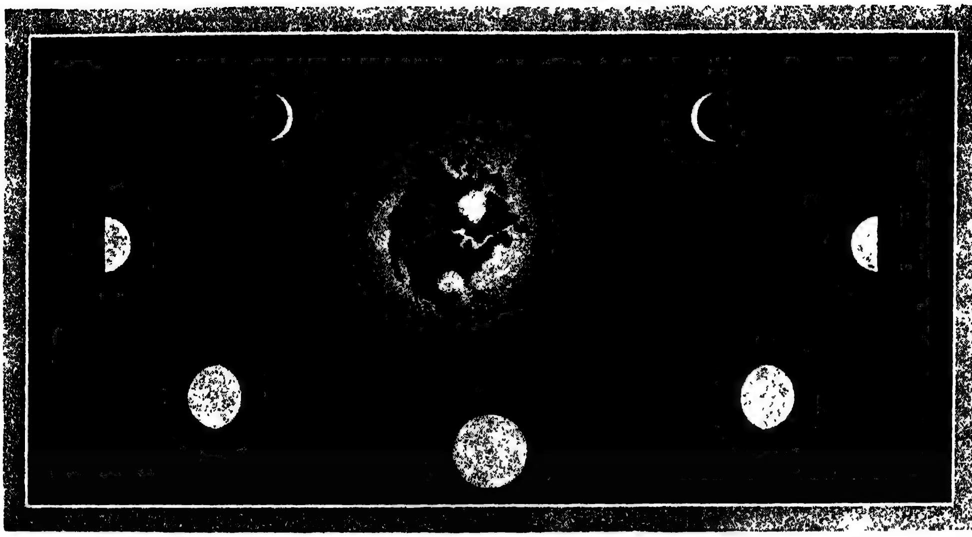
A good many people think that the earth is only four times as large as the moon, since the earth's diameter is only four times greater than the moon's. These pictures show the truth of the matter. Though the moon's diameter is a fourth the diameter of her mother the earth, her total bulk is only about 1/81 of the earth's, as you may see from the scales. If she were set down on top of North America, she would not even cover all of the United States.

It would take four days for a rocket-powered space ship to fly to the moon, for the distance is only about ten times the distance round the earth. But the report of a cannon fired here on the Fourth of July would not be heard there until the eighteenth of the month—and it could be heard then only if our atmosphere could be extended to cover the entire distance, for sound cannot travel without air.

In olden times people believed the moon to be a great ball of fire like the sun, only less hot. We now know that she borrows all her light. In other words, she reflects the light of the sun much as a mirror would if it were fastened in the sky, except that her surface is too rough to reflect the light so perfectly. The reason why we see her after the sun has set is that she is always bathed in light from the sun—just as some part of our earth is always bathed in light.

It takes the moon twenty-nine and one-half days—or what we call a "lunar month"—to complete one of her journeys round the earth. Now it happens that she herself turns exactly once during the same length of time, with the result that she always keeps the same face toward us. Man has never seen the back of the moon; but we cannot be far wrong in guessing that it is not very different from the side we see. If we should ever find that there are people on the planet Mars and learn to communicate with them, one of our requests might be that they send us a wireless photograph of the back of the moon. For they can see what it looks like if they have telescopes.

Her movement with relation to the earth can be illustrated by two persons acting the parts of moon and earth. Suppose you stand in the center of the room and take the part of the earth. You will begin by facing the window; a quarter turn then brings you face to face with the family portrait on the wall; another quarter turn and you are facing the wall opposite the window; and with another turn you are looking into the fourth side of the room. When you turn for the last time you again face the window and have revolved just once. In other words, in your rôle of Mother Earth, you have enacted a complete day—you have turned



The moon never looks the same two days in succession, for as she travels round the earth, she always seems to be changing shape. These eight pictures of her show eight of her "phases" in the course of a month. When the sun is behind her we cannot see her at all, for then the side that is toward us is in shadow—as shown at the top of the page. But as she moves toward the left she begins to reflect the sun from a tiny strip along her side. That is the crescent moon. As she continues her journey she catches more and more of the light until, when she has got halfway round us, her full disk is illuminated by the sun's direct rays—as shown at the bottom of the picture. Then we have the full moon. After that she begins to shrink, or as we say, she is on the wane, until she once more is dark, at the end of the month.

entirely round, in one complete "rotation" (rô-tā′shŭn).

But now we must impersonate the moon. Let us get a little girl to take the part. It will be her duty to walk sideways—and always facing you—around the room, but to do so very slowly, for you must turn twenty-nine and one-half times while she circles round you once. This, you see, is because it takes the moon twenty-nine and one-half days—or twenty-nine and one-half of the earth's rotations—to make a single trip around us.

We Always See the Same Old Face

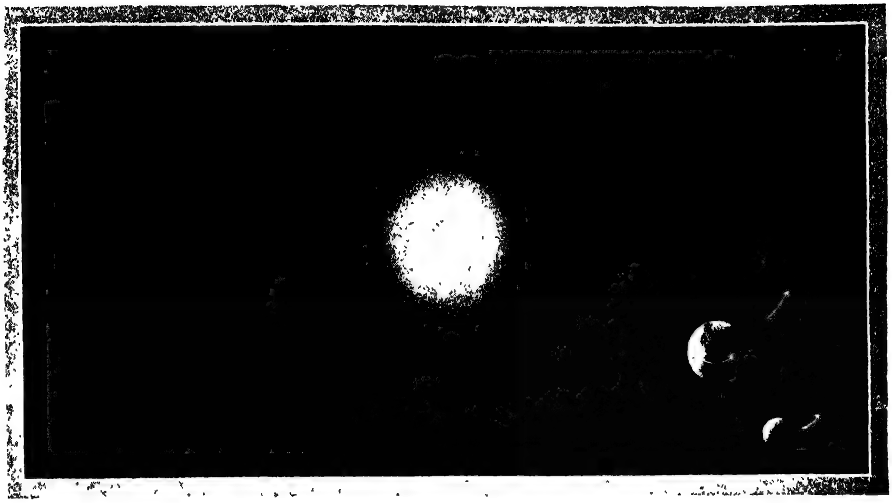
Now let us see what happens. While our little friend sidles slowly from the window to the portrait on the wall—and on around the room till she is back where she began—you will turn completely round twenty-nine and one-half times; and when you have finished doing so, she will once more be back at her starting point under the window. During her trip around the room she has faced once in every direction; in other words, she has turned completely round, just as much as if she had stood on a single spot and faced each of the four walls of the room in turn. Moreover, it has taken her the same length of time to revolve once that it took her to perform her leisurely journey round you; and as a result her face has been turned toward you all the time. You never got a glimpse of the back of her head.

How the Month Got Its Name

This is precisely the way the moon behaves. She makes a complete journey round us in a lunar month, or twenty-nine and one-half days, turning once meanwhile. You will have no difficulty now in seeing that the word "month" must have come from "moon," for a month is roughly reckoned as being thirty days, or about the time it takes the moon to go around us.

But the moon has yet another beautiful and interesting motion. She is constantly circling round the earth, but the earth is meanwhile traveling on its never-ceasing journey round the sun. The moon, in other words, is always being dragged by the earth along its tremendous circuit—or orbit (ôr′-

bit)—through the heavens. This means that the moon cannot circle slowly round and round always in the same path, as our little girl was circling round the room, but is forever dashing breathlessly along to keep with the earth around the sun. Indeed, in the grip of the earth and sun, she even drifts along with him through space at the rate of twelve miles a second. She is a very busy moon.



The sun stands still in the midst of his family of planets, while they all go whirling round him. Here he is shown in the center of the earth's orbit. The earth is moving in the direction of the topmost arrow, and at the same time she is spinning in the direction of the arrow on her surface. Her daughter the moon keeps circling round the earth on a little path of her own in the direction shown by the arrow beside her. And of course since the earth is always moving round the sun, the moon must go round him too.

up with the earth in its mad career. It is as if our boy started to run in a circle round a vacant lot, and kept on whirling at the same time.

The Moon's Path through Space

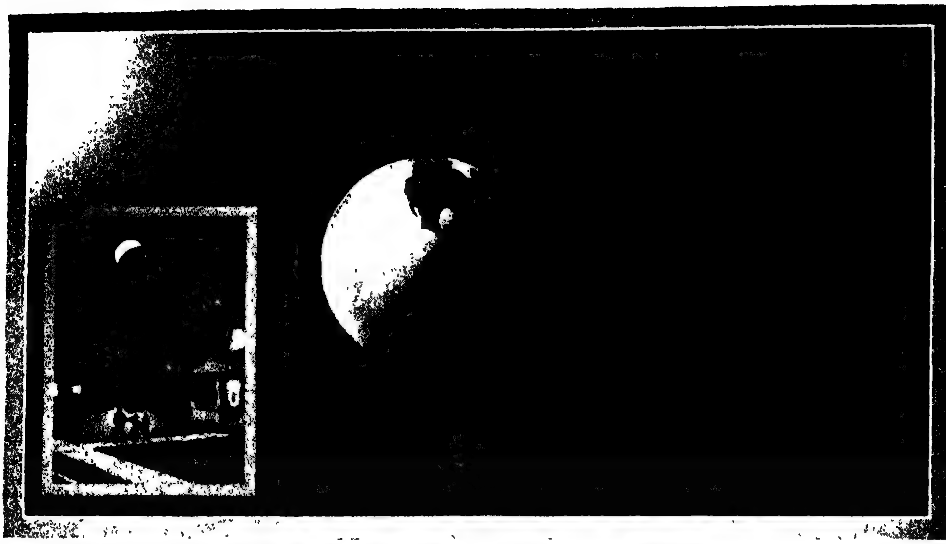
What would happen to his little moon, who would have to keep making circles round him—one circle to every twenty-nine and one-half of his whirls? It is so breathless an undertaking that we are not going to ask you to act it out, but will tell you what would happen. The little girl would be running in the form of a series of beautiful curves. For all the time she is circling around the boy, he is dashing ahead and she must also dash ahead with him; and the result is that her path will look like this: 〰〰〰〰〰〰〰〰〰〰〰〰〰〰 in a big circle all the way round the lot.

This is the pattern of the moon's long path. She rotates herself, she circles round the earth, and in a long curve she travels

Though the moon is usually bathed in sunlight, there are times when the earth gets in the way. This cuts her off from some or all of the light, for the earth then casts a great black shadow over her.

This darkening of the moon is called an eclipse (ē-klĭps′). It can take place only when the moon is full, for only then is she on the opposite side of the earth from the sun, and therefore able to get in the earth's shadow. If the moon's whole disk passes inside the earth's shadow, her light goes out completely and we have a "total eclipse." More often, only a part of her surface lies within the shadow; the rest continues to receive light from the sun and to shine as brilliantly as ever. It is then as if a great round bite had been taken out of her side. This is called a "partial eclipse." In those years when there are five eclipses of the sun there are also two of the moon. It makes a dramatic twelve months.

The cause of an eclipse of the moon is



Whenever the earth comes directly between the moon and the sun, the moon's light is partly or entirely put out. That is what has happened in the big picture above, where the moon is quite inside the earth's shadow—that is, the moon is in "total eclipse." In the small picture, the earth has not yet swung her great bulk squarely between the moon and sun, so the side of the moon that is still outside the earth's shadow is in sunlight—the moon is in "partial eclipse." That great curved shadow shows that the earth is round.

not hard to understand. Hold a ball in your outstretched hand where the light from a lamp behind your head will shine on it. Now swing your arm until the ball enters the shadow cast by your head. The lamp is the sun, your head is the earth, and the ball is the moon. The experiment shows you exactly what happens when the moon, as we say, "passes into eclipse."

The ancients believed, naturally enough, that the moon was constantly changing her shape. We know now that the moon is always round but that we cannot always see the whole of her face. To her varying forms we give the name of "phases." A simple experiment will make the reason for them clear.

Try This Test

Take a seat on a revolving piano stool in a room lighted only by a single lamp, which represents the sun. Your head will be the earth and a white tennis ball held at arm's length in your hand will represent the moon. You will remember that the moon always turns the same face to the earth; so all you have to do is to hold the ball out steadily before you as you turn round on the stool. But you must hold it fairly high, so that your head may not come between the lamp and ball, for that would produce an "eclipse"—which is not the thing we are trying to illustrate.

Why the Moon Is Not Always Round

Suppose you begin your experiment by turning your back to the lamp. As you hold the ball well up before you, the whole half of it that is toward you will be illumined. Your moon is "full." But as you begin turning round, still holding your ball out straight, you will notice that you begin to see less of the illumined half and more of the shaded half. Now your moon is not quite full—it is gibbous (gĭb′ŭs), or "humped." When you have turned a quarter of the way around, only one-half of the ball's face appears to be lighted; you have reached the "half moon" stage, and since your moon is growing smaller she is said to be in her "last quarter," for you see only a fourth of the ball illumined. Now as you turn still farther the lighted portion grows narrower and narrower, until it is only a slender gleaming line—like the "old moon," which may be seen

in the morning to the east or southeast in the heavens.

When you face the lamp, the side of the ball that is toward you is in total darkness – representing the "dark" of the moon. As you turn, however, a thin strip of light again appears; this is the "crescent"—commonly called the "new moon"—which we have all seen low in the western sky in early evening. Now "crescent" (krĕs′ĕnt) is the Latin word for "growing," and is used to designate the moon's first stage, when she is gradually getting larger and larger toward the first quarter, or "half moon." She is at her most beautiful in this stage, which has been described as "the new moon with the old moon in her arms." For one is able to see, not only the gleaming crescent, but the faint outline of a ghostly disk, the whole surface of the moon's face. This comes from the fact that the light which the sun is pouring on the earth is reflected by our planet, just as the moon reflects it. But we are very much larger than the moon and therefore must give off much more light. It is our own light, then, that shines upon the moon and faintly illumines the darker portion of her disk when the sun is not shining on it.

Photo by Yerkes Observatory

Here is that phase of the moon which poets describe as the old moon in the new moon's arms. Only the outermost edge of the moon's disk catches the direct rays of the sun. But we can see the rest of her face in the light that we ourselves reflect to her. For of course the earth is always in sunlight, which is reflected to the moon just as the moon reflects sunlight to us. It is by this light which we ourselves send her that we are able to see those parts of her surface that would otherwise be in total darkness.

It was Leonardo da Vinci (dä vēn′chē), a great artist living in Italy at the same time as Columbus, who first suspected where this pale light came from. When Galileo began to use the telescope, he proved that Leonardo was right.

What Are the Moons Hours?

Now let us return to our piano stool. As we turn slowly round, the crescent, or lighted portion of our tennis ball, grows continually; but the light now appears on the opposite side of the ball from the one on which we saw it when the "moon" was waning. The slender tips of the crescent are called its "horns" or "cusps," and the line joining them on the inside of the curve is called the "terminator" (tûr′mĭ-nā′tẽr).

How Long Does the Moon Shine?

Slowly the crescent grows into another "half moon" turned in the opposite direction from the one it occupied when we were facing the other side of the room. This is called the "first quarter." At both the first and third quarters, the terminator appears to be a straight line. As we turn, the light spreads steadily over the surface of our ball, passing again through the gibbous phase until our backs are squarely to the lamp and our little moon is once more at its full. We have followed it through all its phases. This is exactly what happens to the majestic sphere that sails the heavens.

The crescent moon, as you must have noticed, shines through only a small part of the night, the half moon shines for about half the night, and the full moon shines from sunset until dawn—virtually all night long.

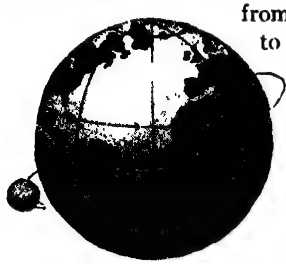
Where and When Does the Moon Rise?

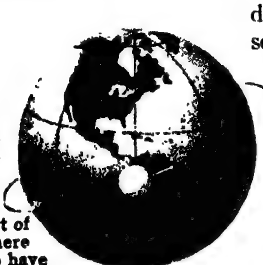
Because the crescent moon is always seen low on the western horizon, certain persons think the moon rises there. But this is a mistake. The rising and setting of the moon have precisely the same cause as the rising and setting of the sun, and therefore both come up in the east. Their seeming movement across the heavens is due to the earth's spinning from west to east, which brings them into view once a day. The moon usually rises about an hour later each day than the day before; though at a certain time every autumn the full moon arrives

at almost the same time for several nights in succession. We speak of this as the "harvest moon"; it occurs within two weeks before or after September 21, the date when days and nights are of equal length. The moon that comes the following month is called the "hunter's moon"; sometimes it does not arrive till early in November.

Curiously enough, the moon is really journeying in just the opposite direction from the one she seems to take. For while she seems to move across the heavens from east to west, she is really traveling in the same direction in which the earth is spinning—that is, from west to east. What really happens is that we are turning so fast as to leave her far behind.

It is as if you were in a fast express train and passed another train going in the same direction but much more slowly. The second train, as you whizzed by, would look as if it were traveling in the opposite direction from your own. People on the Equator are being carried round by the whirling of the earth at the rate of about a thousand miles an hour. Now the moon, it is true, travels around us at a faster pace than this —over twice as fast in fact—but because she is so far away, she seems to be going very much more slowly. She would have to go a good deal faster still in order for us to keep her in sight. So we have the sensation that she is traveling in the opposite direction.





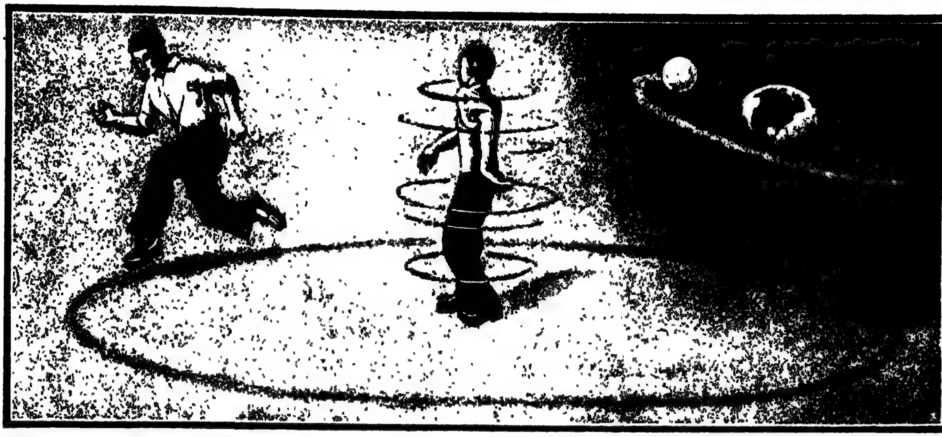
You must often have been startled to see the moon rising in an unexpected place or to see her sailing overhead in a part of the heavens where you seem never to have seen her before. The reason for her changeability lies partly in the fact that her path around the earth does not run parallel with our Equator, but is at an angle with it, as shown above, though at a smaller angle than we have shown here. In these three pictures the moon's path, or orbit, is along the line that runs through her, and the direction of her march is indicated by the arrow. The earth spins in the same direction, but at a somewhat greater speed than the moon's; so as a given spot on earth catches up with the moon and gradually leaves her behind, the moon appears to be traveling across the heavens from east to west. All this—and other very complicated things besides—makes the moon rise at unexpected places. By comparing her position with relation to the three spheres above, you will see that the spot where she rises will depend on the point she has reached in her orbit when the observer on the earth is whirled around by our planet to a position where she comes into view.

This mistake is the easier to make because our own good earth spins round so smoothly that we have no feeling of her moving at all. If her whirling jolted us ever so slightly, we might be able to remember that we are not standing still. As it is, we have to watch the moon for several hours and measure its progress with relation to the stars before we can feel convinced of the direction of its course. But there is a simpler way to gauge it. Draw an imaginary line between the moon's two cusps; she will always be traveling in an easterly direction along a course at right angles to the line.

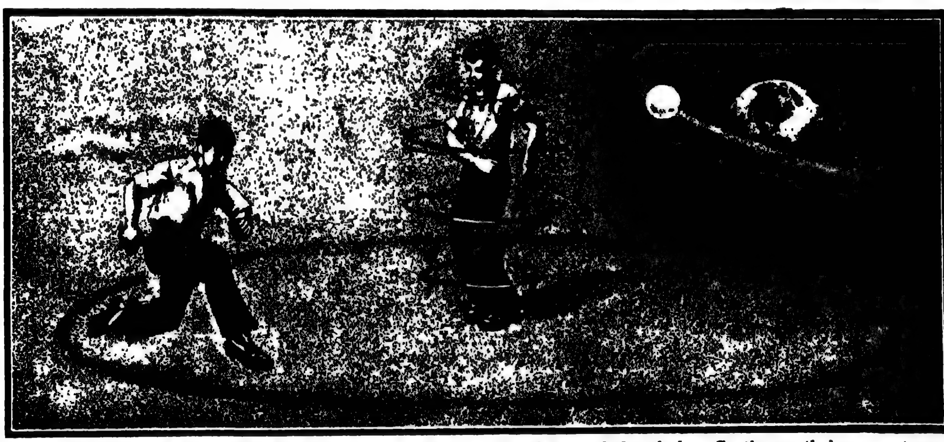
We have just seen that earth and moon are moving in the same direction, only at different speeds. Let us suppose we see the moon rise at seven o'clock of a Monday evening. She travels eastward with us through the heavens, but before daybreak we have left her far behind and she has sunk from sight in the western sky. Our swift rotation brings us back again, however, to seven o'clock on Tuesday night, and we look eagerly to greet her. But she is nowhere to be seen. What has happened to make her late?

Why the Moon Is Late Each Night

It is only this: All the time the moon has been steadily traveling eastward on her orbit round us; and by seven o'clock on Tuesday night she has covered a considerable distance—enough to make us pick her up some fifty minutes later than on Monday night. At ten minutes before eight we catch her glimmer on the eastern horizon, and all



The boy in the center of the circle is representing the earth, so of course he is spinning to his left. The boy running around the circle is acting the part of the moon, so he keeps circling round the earth in the direction shown, but his friend can spin nearly thirty times while he runs around the circle only once.



Let us suppose that the "earth boy" has spun around just once since the upper picture was taken. When he gets back to his first position, facing squarely toward our left, he will no longer find his friend in front of him. For while he was turning, his friend was forging ahead around the circle. So the earth boy must turn a little farther to overtake his friend—and then as he spins on, he will again leave the moon boy behind. So his "moon" will "rise" a little later every day—and every day he will leave it behind on his right.

night long are able to watch her in her majestic journey through the heavens, till our own swift turning has once more left her out of sight. In the same way the moon will lag about fifty minutes every night in putting in her appearance. By this rule, if the moon rises at seven on the evening of June 1, she will rise at six in the morning on June 14—about eleven hours later.

"But how can that be?" someone says, "The moon never shines in the daytime."

Now that is a great mistake. The moon shines in the daytime just as she shines at night, though not with the same splendor, for her glowing brother, the sun, quite dims her pallid rays. We must look hard to find her and then we can make her out only when the sky is very blue. But if you will look at the monthly sky map, you will learn where you can see her as she sails peacefully through the heavens. For except at moments of eclipse the moon never ceases to catch the sun and to bathe us in such light as she is able to send to us from him; and never through all the countless centuries to come, will she be able to desert her staid attendance on the earth, unless it be to fall back into its bosom.

Reading Unit No. 5

THE SILVERY REALM OF MOONLAND

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What are the moon's atmospheric conditions? 1–131-32, 143

What are the surface conditions of the moon? 1–131-32

How does the moon affect the earth? 1–132-43

How does the moon affect the sea? 1–132-43

Is there ever a wet moon? 1–133

How many tides are there each day? 1–133-34

Where do the highest tides occur? 1–134

What is the moon's surface temperature? 1–143

Things to Think About

Why do we have low and high tides?

Why are spring tides the highest?

How is it possible for the moon, which is 240,000 miles away from us, to pull on the oceans?

Why is the moon more nearly round than the earth?

Picture Hunt

What is the arrangement of the earth, moon, and sun during the period of highest tides? 1–134-35

Why does the moon appear larger on the horizon than when it is higher in the sky? 1–132

Related Material

How does the moon affect the earth's rotation? 1–9, 135

How does the sun affect tides? 1–134

How may tides be put to work? 9–442

How do tides affect shipping? 1–137

What is meant by a lunar day? 1–140

How is moon time measured and recorded? 10–478, 480, 481

Practical Applications

How must docks be constructed to take care of great variations in tides? 1–137

How may the energy of the moon be put to work? 12–59

Leisure-time Activities

PROJECT NO. 1: Prepare a silhouette model showing how large the moon appears in a modern telescope, 1–131.

PROJECT NO. 2: Arrange three balls to show the positions of the sun, moon, and earth during spring tides, 1–135.

Summary Statement

The moon circles around the earth in a complicated motion and in doing so causes the tides to rise and fall in our seas.

Some telescopes bring the moon so near that if one could see it that size on the horizon, it would fill a large part of the sky, and the effect would be very much as it is shown in the picture above.

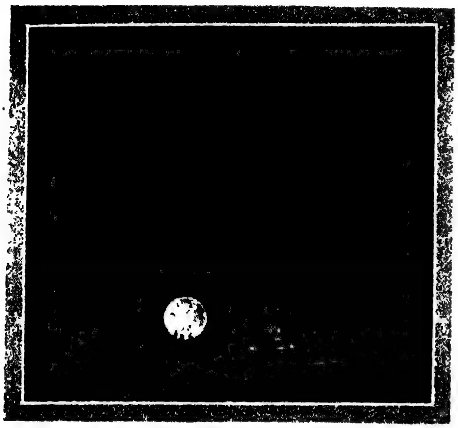
The SILVERY REALM *of* MOONLAND

It Is All a Frozen Desert Where Vast Craters and Mountains Higher than the Alps Make Up the Face of "the Man in the Moon"

THE moon is a mountainous land. Some of her summits are as much as 30,000 feet high—loftier than any peaks on earth. But those imposing crests bear the same names as certain of our own more humble ranges—the Alps and the Carpathians and the Apennines. There is little doubt as to their height. To measure the moon's mountains we need only measure the length of the shadows that they cast; and that is fairly easy, for the shadows on the moon are darker than any earthly shadows. This is because the moon has no atmosphere to spread the light around as it is spread on earth; for instance, when it comes in a window and spreads through all the room. This could never happen on the moon. In the sunshine there it is a little brighter than on earth, but in the shade it is as dark as midnight. Any shadow on the moon is just as black as if there were no sun in the whole universe. We can see the shadows even with the naked eye—for it is they that form the outline of our old familiar friend, the Man in the Moon.

Many thousands of great holes are scattered over the moon's surface. This is true at least of the side that we can see, and astronomers are surely right in their belief that the two sides are very much alike. But there are different theories as to the cause of the great pits. Most of the scientists now think they were made by falling meteors striking the moon with terrific force. Formerly they were thought to be the craters of long-dead volcanoes—though their proportions do not bear out that theory. Still other scientists once thought they might be what re-

mained after the bursting of large bubbles raised by volcanic gases on the moon's "skin" while the globe was still molten. Some of the larger "ring mountains" around the craters look as if they had been built up as coral atolls are in the Pacific. A few of these great lunar holes are a hundred miles across, with walls that are fifty miles thick at the bottom though they grow thinner toward the tops, which are as much as two miles high. We can see the mountains and craters pretty well with a pair of opera glasses.



Cover the picture at the right with your hand. Does the moon look very large to you—as large as a city block, or even big enough to contain a village? If so, she seems large because you measure her against the trees and houses near her on the horizon.

Cover the left-hand picture and look at this moon. How large does she look—a little bigger than the house, or only the size of a cart wheel or a dish pan? The moon is said to look smaller when she is high because there is nothing for the eye to measure her by.

There are other mysterious markings on the moon's white face—shapes which look like the beds of ancient rivers and of oceans that have been dry for thousands upon thousands of years. For the moon is a dead world—without a breath of air or a drop of water and long since gone cold. Many persons think our own old earth will some day be like that; so for this added reason the moon is interesting to us and the object of a great deal of study the part of learned men.

"Seas," "Rays," and "Rills"

What were once taken for ocean beds—and so were called "maria," the Latin word for "seas"—are now believed to be gigantic areas that were covered by a flow of liquid rock. This welled up from the moon's interior when a vast meteor broke the moon's crust. Such areas are too smooth to be the beds of old oceans.

Then there are the "rills"—puzzling deep chasms taking their name from the German "Rille," or "groove." They are narrow and often long, and they seem to have no relation to the mountains and craters they cross. Maybe they are just cracks.

The "rays" are very bright streaks always radiating from a crater. Sometimes they run for a hundred miles straight across mountain and "sea." They might be splashes from an iron meteorite melted by its impact.

The Shape of the Moon

Except for comets and the nebulae, all the heavenly bodies known to the astronomers are spherical, or nearly so. This means that they are round like a ball, except in those cases, such as the earth's, when rapid whirling in a molten state has made them bulge at the Equator. Jupiter and Saturn are so much larger round the waist that a telescope will show it plainly, but on the earth the bulge is so slight that it could not be seen. For though the earth is orange-shaped, it is only twenty-seven miles shorter from pole to pole than it is through the Equator; and on a body 8,000 miles through, so slight a variation is hardly to be reckoned with. The moon has probably always been

It is strange to think that New York - and every other spot on the surface of the earth - is jerked up and down just a bit whenever the moon passes overhead. Of course the amount of the movement has been enormously exaggerated in this picture, in order to make it clear. But slight as the rise and fall may be, it nevertheless takes place—and all on account of the tremendous tug the moon gives a spot as she passes it.

perfectly round, for it turns so slowly that its whirling could hardly force it out of shape. The huge sun, too, shows no flattening, so far as our measurements have shown. Its movement is very slow and stately; a complete rotation takes almost a month.

Is There Ever a Wet Moon?

"There is a wet moon," you have heard people say. "We surely shall have rain!"

Now sometimes they were right and sometimes wrong, but at least we may be sure of one thing: they did not mean that the moon itself was moist. For it is waterless; there is not a drop of liquid on it. But sometimes you see a soft, dim halo round its face. This does not come from the moon's atmosphere, for she is as devoid of air as she is of water. But if our own air is watery, the moon will be shining on us through a filmy veil. Of course she is 240,000 miles away from the veil, which is right here in our atmosphere. The halo is made in our own air and may be only a few hundred feet above us.

So at least our own air is moist, and our friends may not be far wrong in their prophecy, since moisture often condenses into rain. It may indeed be a "wet moon."

One of the most striking and relentless forces in all nature is the coming and going of the tides—the rise and fall, twice a day, of the gigantic seas all around the world. It is not because we do not know the reason for the tides that they are so impressive, for we know it well enough. But the relentless creeping up and up of water all along the shore, and its sulky retreat down the long line of sand, make any person sitting on the beach feel very puny in the face of such a force.

How Many Tides Each Day?

It would not take you long at the seashore to notice that the tide takes about six and a half hours to rise or fall. Only a little

figuring, therefore, will show you that the tides will come noticeably later every day, but that there will be two high tides and two low tides every twenty-five hours—unless you happen to be watching them in one of the places where, for various reasons, the tides may be unequal.

The Force That Makes the Tides

Centuries ago—before the time of Christ—people had found out that it was the moon that caused the tides, but how it did so they could not imagine. In fact, it was less than three hundred years ago that the mystery was explained. Then Sir Isaac Newton discovered the enormous force called gravitation (grăv′ĭ-tā′shŭn) by which the heavenly bodies grasp each other across thousands of miles of space. The matter of the tides then became quite simple.

The moon, as you know, is constantly pulling on the earth—just as the earth is pulling on the moon. As a result, whenever the earth turns the watery part of her surface toward the moon, the pull of the moon tends to draw the loose water up into a heap. And since the earth spins eastward under the moon, the heap of water travels westward, following the moon. It resembles a great wave and is known as the "direct tide"—the tide that is nearest the moon.

Why We Have High Tides

For there are two high tides at any one time—one on the side of the earth toward the moon and one on the opposite side. We might think that the moon could attract only the water on the nearer side, but as a matter of fact it causes a bulge in the water on the other side also—for it tends to pull the earth itself away from the loose water on the farther side. Then this water rises into a wave and is known as the "opposite tide."

At first thought it would seem that if a relatively small body like the moon can cause such a disturbance as the tides, a huge mass like the sun ought to produce a still greater effect. Now it is indeed true that the sun is far larger than the moon, but, on the other hand, it is nearly four hundred times farther away from us. Its distance more than makes up for its size, with the result that the little moon is more than twice as powerful a tide maker as the sun.

But that the sun also has a tidal effect is proved by the fact that, when the sun and moon are on the same side of the earth or on opposite sides, and can pull together, the tides are unusually high. This happens twice a month—around the new moon and around the full moon—and gives us what we know as "spring tides," because they spring high into the air.

Why We Have Low Tides

But when the sun and moon are pulling at right angles to each other—as happens when the moon is in its first and last quarters—the tides are very low. They are then called "neap tides," from an Old English word meaning "low" or "scant."

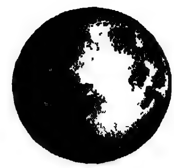
The height of the tides varies greatly in different places. On the Island of St. Helena, they rise only some three feet; but in the Bay of Fundy, where there is a shallow coast and narrowing bays, they often rise and fall over fifty feet. Even lakes and rivers have tides, for the moon tugs at every part of the earth's surface; but when a body of water is small, the tide in it is so slight that it is almost impossible to see.

The Great Lakes have an ebb and flow of about two inches; and even the tea in our cups must rise and fall as the moon passes over them.

What Caesar Thought of the Tide

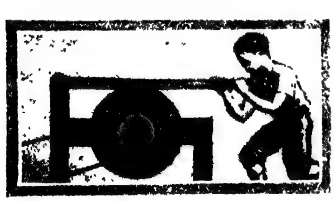
It happened that Julius Caesar, when he was embarking with his troops to invade Great Britain, encountered a very high spring tide. He assured his men that it was caused by the full moon. It is doubtful whether he knew the true cause. He was right, of course, in that a spring tide will come when the moon is at its full, for the moon and the sun are then on opposite sides of the earth; but that it was this that caused the high tide, rather than the full moon, he probably did not suspect. We now know that, whether the moon is full or a mere crescent, it never fails to pull

When the moon is on a line between the sun and the earth, as shown at the left, we have very high tides, or "spring" tides. That is because both sun and moon have joined forces, and the combined pull is stronger than the pull of the moon alone, which ordinarily causes the tides. Of course the extent to which the earth bulges under their pull is very much exaggerated in the picture.



As the moon passes round the earth, she tugs at the earth with such force that she raises the ocean in a great wave on the side of the earth toward her, and another great wave rises in the ocean on the side opposite her. In the picture of the earth at the left you may see how the waters bulge under the pull of the little moon in the upper right-hand corner. Of course the size of the bulge is greatly exaggerated here. This bulge follows the moon as she passes around the earth, and is what causes the tides, which really are nothing more than great waves that pass over the earth's oceans twice a day.

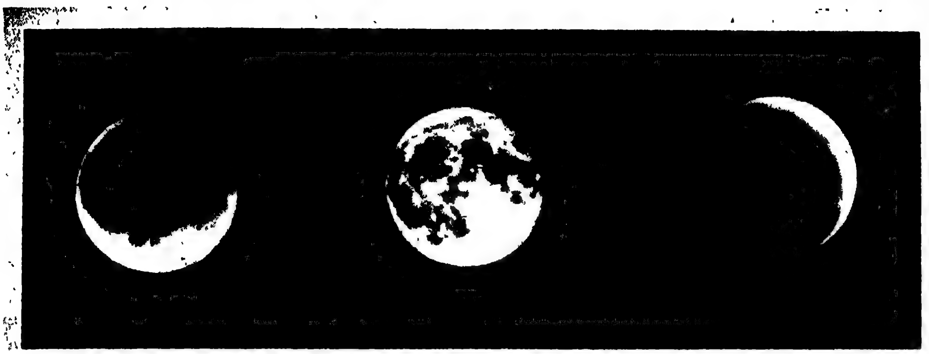
The moon's pull slows up the spinning earth just as surely as the brake slows up the turning wheel in the lower left-hand corner.



with the same force upon the earth; for it is always there in its whole bulk, no matter how much or little of it we can see.

If there were oceans on the moon, the tides there would be vastly greater than those on the earth, because the earth is so much greater than the moon.

In recent years astronomers have learned that the tides are very gradually slowing up the earth's rotation. The constant holding back of such a vast quantity of water drags on the whirling planet just as a brake drags on a wheel—or we had better say a feather on a whirling cannon ball. The



Here are three pictures of the moon, illustrating the three different ways in which the moon may get her light. In the picture at the left she is shown in total eclipse; that is to say, no single ray of the sun's light reaches her, for the earth is squarely between her and the sun. To the naked eye she would be invisible, but the keen eye of the telescope can see her lit up with a pale coppery glow by light that the earth's atmosphere bends out of its straight path and sends to the moon. That is called refracted light; it is reddish because our atmosphere robs the light of all its bluish rays, and so leaves only the red ones. The full moon in the central picture is receiving the sun's rays over its whole disk, and like a mirror is reflecting them to us. It is that reflected light which we on earth see. In the picture on the right the crescent moon is shining in the direct rays of the sun, which it in turn reflects to us. But the rest of the disk is lighted up by rays which the earth reflects upon the moon after receiving them from the sun. So this "old" moon, which we see "in the new moon's arms," is said to be earth-lit—though of course in all these three cases the moon's light comes originally from that great central fire, the sun.

effect is ever so slight—too small, perhaps, for measurement; yet during the course of millions of years it will be felt. And what will happen then? Well, for one thing, the moon will move farther and farther away and the tides become smaller and smaller, as long as there is water on the earth to ebb and flow; though if all the water on the earth should dry up and the earth became a rigid body, the moon would be held at a fixed distance.

A Struggle between Earth and Moon

And after that there would begin—if certain astronomers are right—a long struggle between the moon's centrifugal force, which continually drags it out into space, and the relentless pull of the earth's gravitation. In this great contest it is thought that gravitation would win. In other words, some day the moon will come crashing back to earth, with a tremendous spattering of oceans and shattering of rocks—and everything upon the earth's calm face will burst into flames. But it is nothing that you and I need worry about. For even if the learned guess is right, the moon will fall so many billions of years hence that it is doubtful if mankind, as we know it, will still be living here.

For in the course of all these changes, the earth will also have slowed down in the speed of her rotation. She will even reach a stage at which she will turn round only once a month; her day will then be over four weeks long. When this shall have happened, the moon will never rise and set, but will always seem to be fixed at the same spot in the heavens, no matter whether it be day or night, for we shall not be whirling fast enough to leave her behind. As a result, those who are so unlucky as to be living on the side of the earth away from the moon will never see her. It may well be, however, that in that day no living soul will be left, for the earth may then have come to be a lifeless planet, with one half turned away from the sun for two weeks on end and therefore frozen solid, and the other half burned to a tinder by two weeks of unrelenting heat.

But this is all a guess and it may never come to pass.

A Trip to the Moon

Come, let us fly away to call on the Man in the Moon!

"But it cannot be done," you say.

Yes, there is a way to do it. We may all of us order up a swift rocket called Imag-

The oval above shows a sailing vessel drawn up at high tide beside the very same wharves that are shown tall and bare at low tide in the large picture.

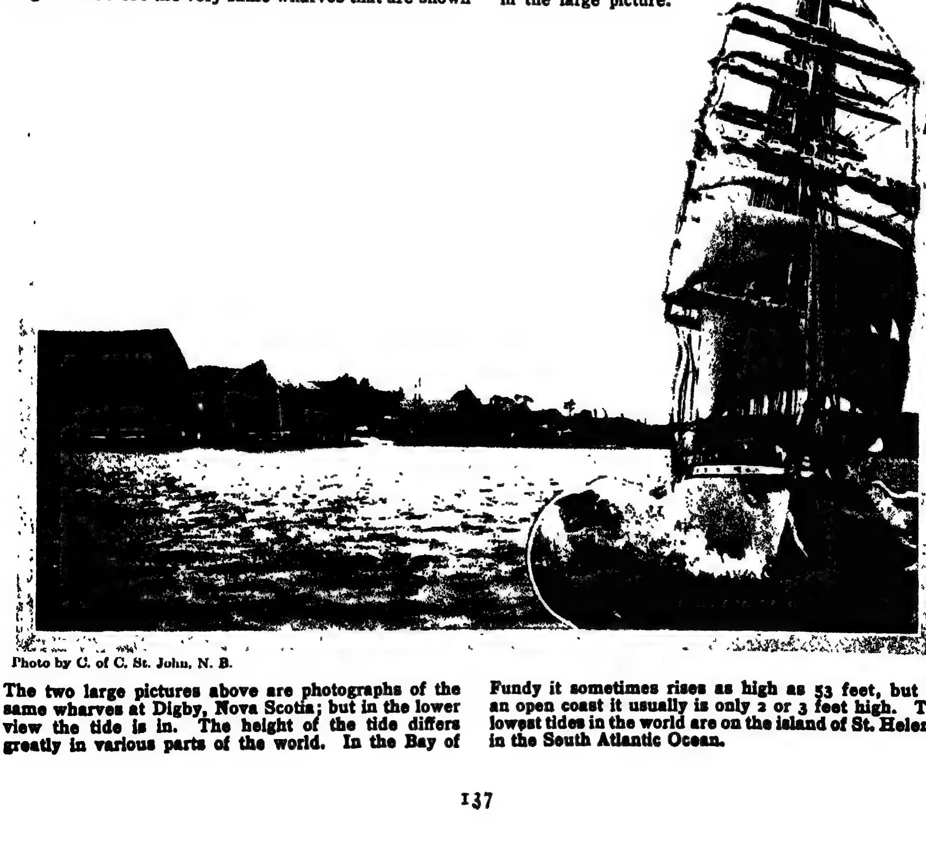


Photo by C. of C. St. John, N. B.

The two large pictures above are photographs of the same wharves at Digby, Nova Scotia; but in the lower view the tide is in. The height of the tide differs greatly in various parts of the world. In the Bay of Fundy it sometimes rises as high as 53 feet, but on an open coast it usually is only 2 or 3 feet high. The lowest tides in the world are on the island of St. Helena, in the South Atlantic Ocean.

ination, and sit snug and warm in it at home while we travel far out into the vast reaches above us that are called space. Our slender rocket must be well supplied with food and air and water, for there will be none of these necessaries on the moon; and we must dress in cold-proof clothing to withstand the frigid temperatures we shall meet. But it does not take the imagination long to supply these little needs; so with a good-by to our friends we launch out boldly into space.

Nothing unusual happens during the first few miles of our journey. The green earth gradually sinks until it looks like a vast plain whose outer borders fade away in mist. As we rise higher and higher the instrument board shows that we are leaving the earth's

atmosphere behind. But we feel no discomfort, for we are supplied with oxygen and the air inside the rocket is kept at normal pressure.

Here we are on our way to the moon—the little ball toward which our rocket is pointing. When we look through one of the portholes at Mother Earth lying far behind us, we find that she is just a great round disk with a few rivers and mountains and lakes traced on her surface. These too finally disappear.

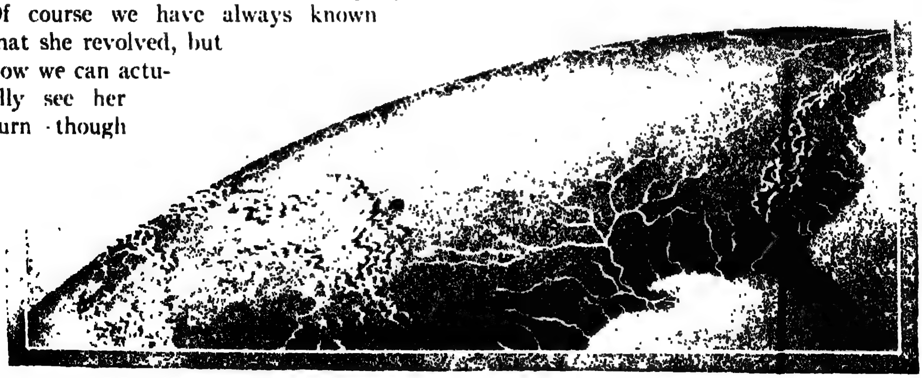
Higher and higher we climb. It is bitterly cold outside, and all around us is blackest night except for the blinding path of light that leads up to the sun—for without air there is no daylight. Our pilot lets us look through the telescope he has trained on the planet we have left. What a gorgeous sight! There is Mother Earth spinning majestically beneath us—much as a top spins. Of course we have always known that she revolved, but now we can actually see her turn—though at this distance she seems to do it very, very slowly.

Naturally it gives us rather a start to see our native world so far away. But this is nothing to our amazement when our pilot tells us about the rocket we are in. First he calls our attention to the fact that it is full of growing plants. These, he explains, help to keep the air fit for us to breathe. For plants use carbon dioxide (dī-ŏk'sīd)—a poisonous gas that our lungs give off—and in turn release oxygen, which we must have to breathe. So we do not need to carry so large a supply of oxygen with us. He shows us, too, the system by which the moisture from our breath is turned into drinking water.

When Mother Earth Becomes a Moon

There is so much to see and learn about inside our amazing rocket that the hours speed by unnoticed. Suddenly someone happens to glance at the moon. To our great surprise we see her lying out of our course entirely—away to the west of the direction in which we are traveling. But our pilot hastens to relieve our dismay by explaining that if we continue at our present whizzing speed the moon's own march will have brought her directly in our path by the time we are 240,000 miles from the earth.

We dash full speed ahead, watching the distant stars, which stand out vividly because we do not have to look through the earth's dense atmosphere. Suddenly someone looks behind and gives a mighty shout. There is an enormous bright disk swinging



In the large picture is a scientist's idea of what scenery must be like on the moon. We know that he cannot be far wrong, though no one has ever gone there to paint or photograph it. After all, those mountains are not very different from the ones shown in the small photograph, which was taken in America.

along under us. Our patient pilot explains that there is no reason for surprise. We are only looking at our own old earth, now reflecting the sunlight for us just as we have seen the moon do all our lives. But what a magnificent sight she is! For she is many times larger than the moon and we are much nearer to her besides!

Landing on the Moon

But the time goes fast. Before we realize it four days have passed, and here is the moon directly in our path. You can guess how eagerly we scan her rugged face. We turn the rocket's tail toward the moon and start the motors. They counteract the moon's gravitational pull, and we settle easily down on her surface with the rocket's nose straight in the air. If we had been landing on a planet we should have had to shoot by it and circle back in order to brake for landing. For planets, since they are larger than the moon, would pull at us with much greater force. Our motors alone could never keep us from crashing.

Our pilot explains that the moon has not a drop of water on her anywhere, that it is doubtful if she ever has had. The so-called "seas" shown on maps of the moon are only dark patches that go to form the face of the Man in the Moon. Moreover, the moon has no air. So unless we use instruments which he now gives us, we shall not be able to talk together. Our voices will not carry. Our lips will move but will make no sound.

At last all is made ready and we are able to land. We jump eagerly to earth—or rather we should say "to moon." But to our amazement we come down a hundred feet away.

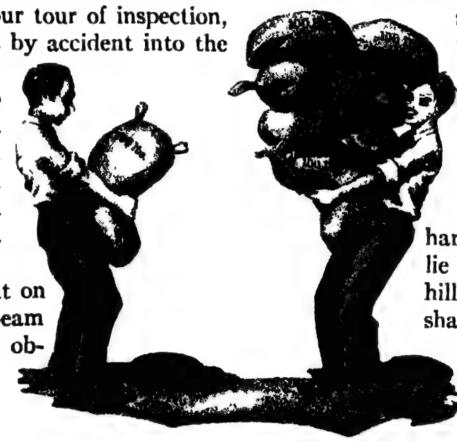
Exploring the Moon

"It is all very simple," our smiling guide explains. "The moon is so much smaller than the earth, and therefore pulls us so much less, that we can jump much farther—though of course we don't come down any harder. That is all."

Then, too, there is no air here to offer resistance to our forward motion. At home

the thick blanket of air—which weighs fifteen pounds to the square inch—holds us back whether we walk or run or jump or fly. Whenever we move swiftly we can feel its force against our faces—like a wind. It is not unlike the resistance that we feel when wading in the water; only it is not so great because the air is not so dense as water—and we are a good deal less conscious of it because we are so well used to it.

As we start off on our tour of inspection, one of our party steps by accident into the shadow of a huge rock. Instantly he is lost to view, hidden in total darkness. On our earth the atmosphere will spread a ray of light over a much larger area than the one it is directly shining on. But on the airless moon a sunbeam can illumine only the objects that it strikes. All others are blotted out as if they had no existence. If our earth were so unfortunate as to possess no atmosphere, we should have black night the instant after sunset, and neither dawn nor twilight. As it is, we have a long and gracious period of gloaming added to the day at either end; for even after sunset our atmosphere absorbs and scatters and reflects the light that the departed sun is still sending up into the sky from just below the horizon.



Anyone could be an athlete if he lived on the moon. The boy at the left, who is struggling under the weight of a hundred pounds, has suddenly become a strong man when he finds himself on the moon, as shown on the right, for now he can carry with ease a weight of six hundred pounds.

Behold! the Crescent Earth

We summon our vanished friend and then begin to scan the sky in search of Mother Earth. And lo! we behold her as a mighty crescent, gleaming against a coal-black heaven—for it is atmosphere that gives our earth its bright blue sky. We might have known that she would look like that, for, if we remember our experiment with the lamp and tennis ball, we shall know why a person on the moon would see the earth go through the same phases that we see the moon pass through. But they are, as we say, "complementary": the "full earth" would occur at the time of the new moon, the earth's first quarter would fall at the time of the moon's third quarter, and so on, with all the phases just reversed. It seems almost unbelievable that this gleaming crescent, showing a bit of the great ice caps at the North and South Poles, should be our good green earth.

But what a dazzling radiance the sun sheds! It is much brighter than on our earth, for the rays are not obliged to penetrate a thick blanket of atmosphere. Glittering they fall from the inky sky upon the lifeless surface round us, and hard and black the shadows lie behind every rock and hill and mountain, with a sharp edge such as shadows never have on earth.

We amuse ourselves by looking down a neighboring "crater" (krā'tẽr) though it is not the mouth of a volcano. What a hole! It is a hundred miles across. We ascend a mighty peak 36,000 feet above the plain—how easy it is to climb on the moon! With perfect ease we can pick up and toss big stones that we could hardly lift at home. Our guide tells us that on the earth he weighs 168 pounds but that here in moonland he weighs only 28. For since the moon is much smaller than the earth, she cannot hold an object with anything like so strong a grasp. As we have said before, a body's gravitational pull—or its attraction for other bodies—depends upon its size as well as on its distance from them.

It is now the end of a lunar day—perfect, as all lunar days are perfect, in its cloudless brilliance, and almost fifteen of our earthly days in length. We have enjoyed some 354 hours of ceaseless sunshine. Even so we should have perished but for our cold-proof clothes. For on the moon there is no quilt of air to hold the least bit of the heat

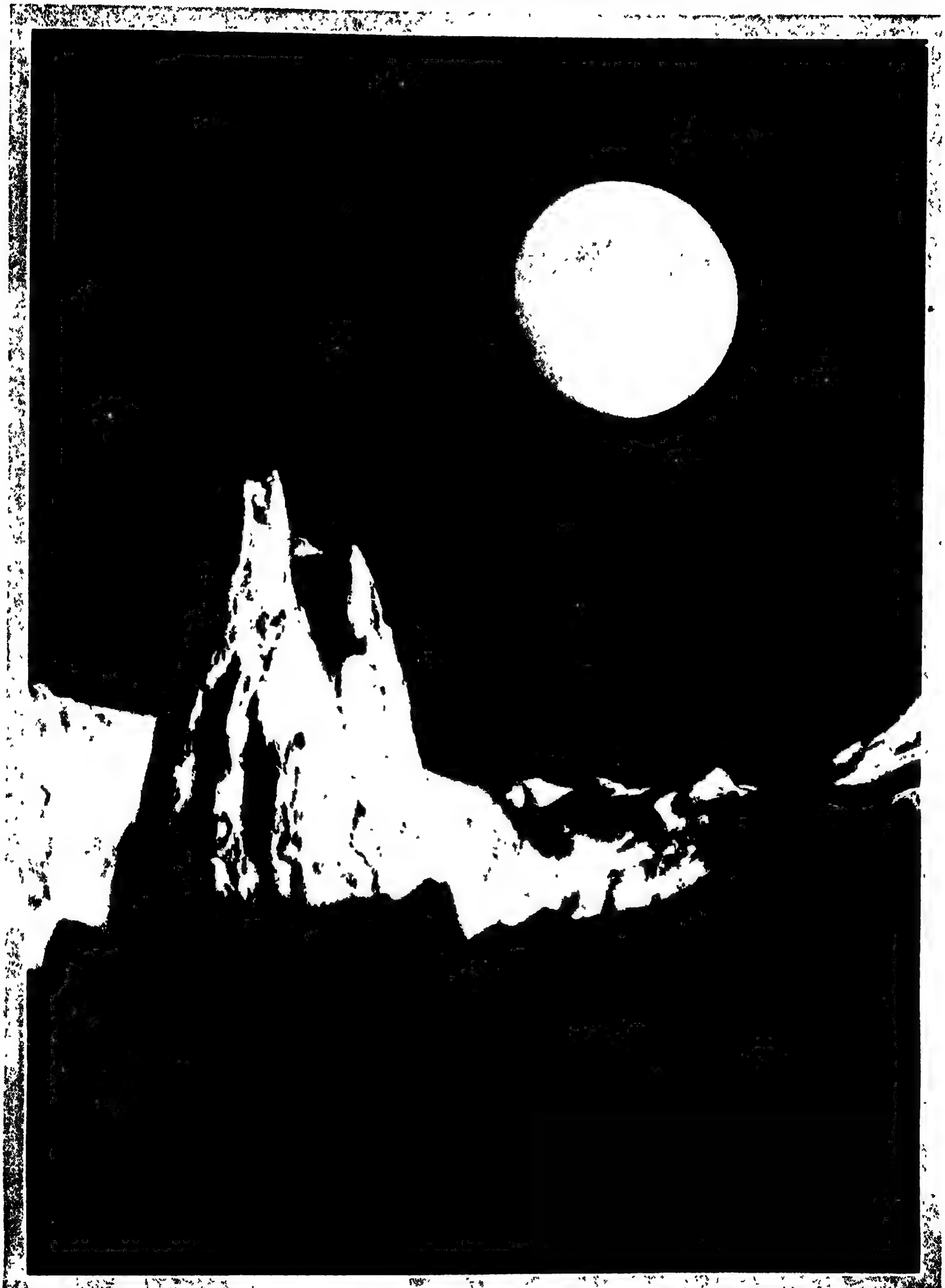


Photo by American Museum of Natural History

When we see the moon's thin crescent in the evening sky, it does not often occur to us that to her our own old earth shines with a radiance that must be dazzling. For of course we reflect the sun's light to her, just as she reflects it to us. The picture above will give you a very good idea of what a landscape on the moon must be like. Though it is daytime, the sky is inky black, for the moon has no atmosphere to spread out the light into a bright glow. The stars are out day and night, and the "full earth" shines majestically.

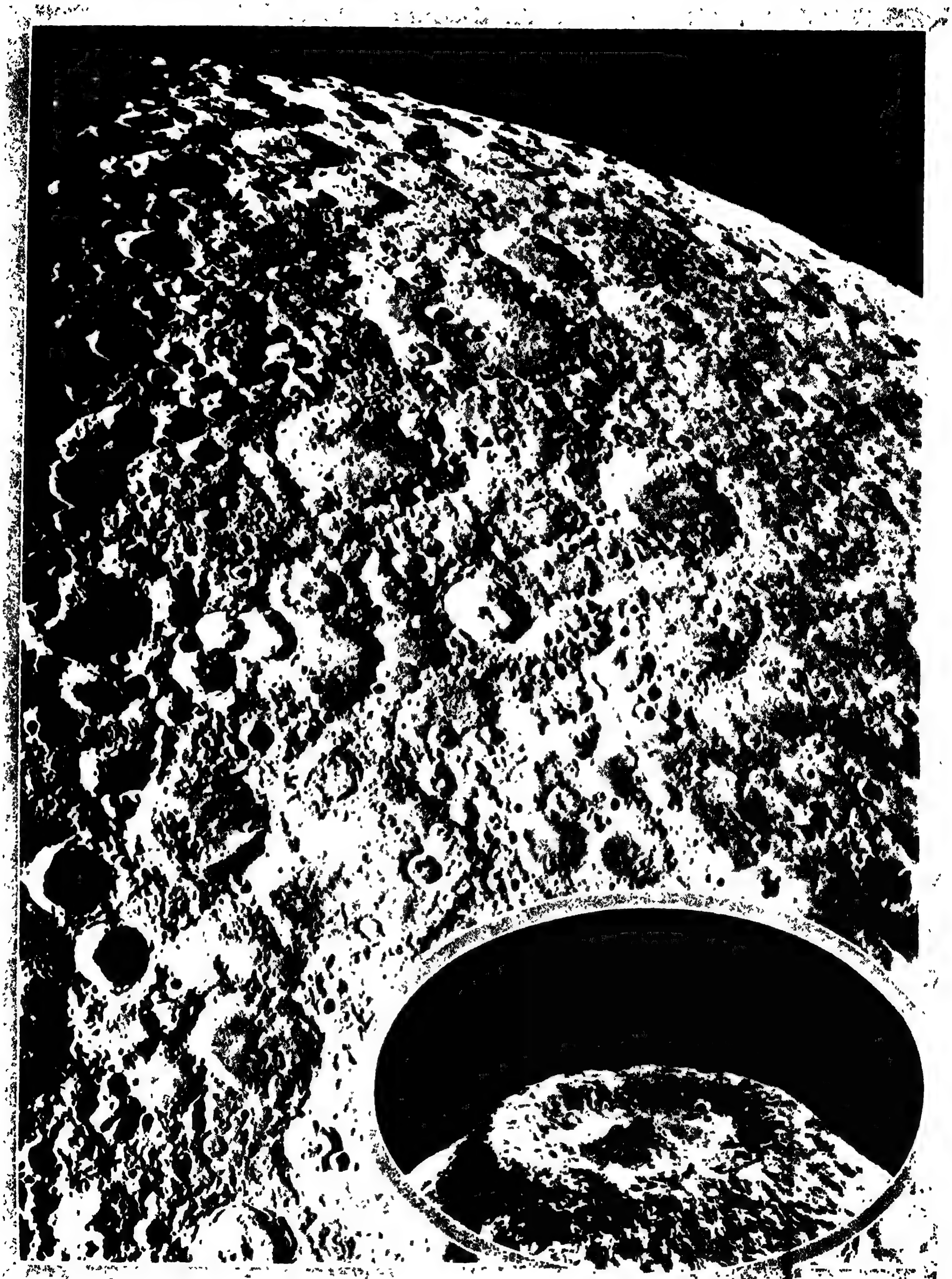


Photo by Yerkes Observatory

A number of telescopes bring the moon as near as it is shown in the large picture, which will give you an idea of what the moon's surface looks like. Those great craters were not formed by volcanoes but by giant meteors dashing into the moon with terrific force. The ones with sharp outlines are the newer ones. Notice how black the shadows are. The inset shows how one of the small craters may look.

[illegible] by Yerkes Observatory

This is a very lifelike photograph of the face of the Man in the Moon. Of course it was taken through a telescope, but you will be amazed to find how distinctly you can see him through a good pair of field or opera glasses. If you look at the moon when it is a crescent some three or four days old you will have no trouble in seeing the mountains that stand out along the crescent's inner side. Of course all those pock-marks are craters caused by meteorites striking the moon. The large dark patches are the "seas" that never were seas at all but were probably caused by the spread of molten rock. The "rays" or bright lines radiating from a crater show clearly near the large crater not far from the center of the picture. The black dots are shadows cast by mountains. From noon to midnight the moon's temperature varies nearly 600° F.

that the sun is pouring down. If a thing is in the sunshine it is hot, but if it is in a shadow it will be freezing instantly for exactly the same reason that it will be pitch dark. So there can be no way of keeping warm on the moon. Even if one side of us were hot, the other side would be frozen stiff! For the temperature on that side would be hundreds of degrees below zero.

Someone suggests that we explore the moon's hidden side, which no one on the earth has ever seen, because the moon always turns the same face to us. But most of us shudder at the thought of facing the hardships of the long lunar night. So we climb aboard our swift rocket and just as the sun is sinking over the moon's western edge, we dash back toward the earth and our own cozy nook by the fire, there to ponder all the marvels we have seen.

Reading Unit No. 6

TRAVELS IN OTHER WORLDS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Which is the smallest planet? 1–146

Why is one side of the planet Mercury hot and the other side cold? 1–146-47

Aside from the sun and moon, which is the brightest object in the sky? 1–148

Which planet is sometimes referred to as the earth's twin planet? 1–148-49

Which planet is nearest to the earth? 1–148

On which planet is the year 687 days long? 1–150-51

Why are the moons of Mars considered queer? 1–151

Things to Think About

How could one boy play a game of baseball with himself on one of the moons of Mars?

Are there men on Mars?

Why might people on Mars have need of canals?

Why is a day as long as a year on Venus?

Picture Hunt

How is the "transit of Venus" between the earth and the sun used to check the distance between them? 1–148-49

Why did some people think that there might be life on Mars? 1–152

Related Material

What is believed to be the origin of the planets? 1–1-11

Was a planet ever destroyed? 1–6

How did Captain Cook, the great English explorer, help astronomers? 13–489

What are the gravitational conditions on Mars? 1–301-2

Which planet has polar conditions similar to those on the earth? 13–404

How were the names of the planets taken from Grecian mythology? 1–109, 147, 154, 155, 158

Leisure-time Activities

PROJECT NO. 1: Make a clay model of the surface of Mars, 1–152.

PROJECT NO. 2: Show your friends how the "transit" of Venus or Mercury could be observed with a lens and a mirror, 1–146, 148.

Summary Statement

Venus, Mercury, and Mars are the three planets in the solar system which are the nearest neighbors to the earth.

From a painting by Chesley Bonestell for the book THE CONQ[illegible] OF SPACE, by Chesley Bonestell and Willy Ley, published by The Viking Press [illegible] 1949

Scientists believe that if we could travel by space ship to Mercury the landscapes we should see there would look a good deal like the one Mr. Bonestell has shown here. The sun would look three times as large as we see it on earth, and since the planet always turns the same side to the sun the heat on that side would be terrific probably high enough to melt lead. Asbestos suits would not protect us very long there.

From a painting by Chesley Bonestell for the book THE CONQUEST OF SPACE by Chesley Bonestell and Willy Ley, published by The Viking Press, © C B 1947

Until lately scientists thought that Venus had a hot, moist climate. Now they feel sure that the clouds in which she is veiled contain little or no water vapor. So she must be a reddish desert, with a surface that looks much as Mr. Bonestell, the artist, shows it above—a strange, parched, windswept world of swirling sand and fantastic wind-carved rocks. The clouds almost never part to show the sun.

Who has not lain on his back of a clear summer day and looked into the cloudless sky above? And who, as he lay there, has ever remembered that countless stars he could not see were swimming there before him?

TRAVELS *in* OTHER WORLDS

Some of Them a Thousand Times as Big as Ours and Some of Them So Tiny That We Could Walk All the Way around Them in a Morning

MAN has always been exploring. The need of food and the desire for riches or adventure have from the earliest times sent him wandering into the wilderness or sailing over the uncharted seas. The names of the earliest explorers are all unknown to us, but they are none the less deserving of our gratitude and admiration.

And now at last the earth is almost conquered. Seas, jungles, and the frigid poles have given up most of their secrets. But are exploration and adventure dead? No, in one sense they have just begun! For there are still exciting expeditions of the mind into worlds so unlike ours as to stagger the imagination. The explorers of our own familiar planet never found conditions greatly differing from those at home. Hot and cold, moist and dry, offered about the only change. It was the same old earth wherever they might go.

But scattered through the heavens there are worlds so strange that the most learned men are at a loss to know some of the simplest facts about them. The earth, which man has so thoroughly explored, is one of the smaller bodies in the universe and perhaps one of the less important. Even from the nearest planet she would be no more than a tiny point of light, and from the farther ones she could not be seen at all.

If this is our relation to the planets, which in comparison with the stars are in our own front yard, imagine our littleness in the scheme of the whole universe. For if the sun and earth and her eight sister planets,

with all their moons, and all the meteors and comets were rolled into one huge ball as bright as the sun, the ball would still be too small to see from many of the distant stars.

Which Is the Smallest Planet?

Such is the size of the universe. But we need not worry for the moment about the suns so far away they cannot see us. Our trip of exploration will be long and strange enough if we only call on the planets right around us. We cannot do better than begin with the one we know as Mercury. Like all the other planets, it is just a world like ours. It is not a sun, as are the stars, and it shines only because the sun is shining on it as it circles round him.

On these scales we have our own earth at the right, and on the other balance twenty-five small planets each one the size of Mercury. Yet they do not tip the beam.

We do not know who first discovered the little twinkling planet Mercury (mûr'kû-rĭ)—probably a man in the Stone Age. The Assyrians and the Greeks knew the little fellow well and called him the evening star—visible for only a few hours on the westerly horizon during the early evening of certain days. But they also noticed that he had a twin of similar habits and appearance, who at other seasons of the year twinkled over the eastern horizon just before sunrise. They called the twin Apollo, or the morning star. It was not till men had learned a great deal more about the heavenly bodies that they found out that Mercury and Apollo were the same "star"—and not a star at all, but rather the baby in the sun's family of planets. According to the season of the year, he is visible in the evening in the west or in the morning in the east. He is hard to study, for he is so near the sun that he is lost in its vivid light.

But we know certain facts about him. His diameter is only 3,100 miles—less than half that of the earth. We rarely see him with the unaided eye, for he keeps so near his parent sun that except in the soft twilight his little glimmer is lost in the brighter light. His year is eighty-eight days long; that is, he is so near the sun that he can circle round it in very much less time than we. He is the swiftest, too, of all the planets, for he dashes along at an average speed of twenty-nine miles a second. During his journey round the sun, he himself turns round just once—or, as we say, he rotates once upon his axis; for the axis (ăk'-sĭs) is an imaginary line, drawn through a sphere from pole to pole, around which a body spins. Mercury's day and year are therefore equal in length, just as the moon's are; and he can never turn but one face to the sun. So on one side of him it must be always day, and on the other side eternal night.

Because the little fellow goes around the sun some four times to our once, he has to pass between us and the sun; and he has phases, just as the moon has, since he shines only with the light he can reflect from the sun. At rare times it happens that in passing us he gets right in a line between us and the sun, and through the telescope we can then see him as a very small black dot traveling slowly across the sun's bright disk. If he were larger he would cause an eclipse, but since he is so tiny we call it a "transit of Mercury." There was a transit in May, 1924, and in November, 1927; and another in May, 1937. The first was seven hours and fifty minutes long, almost as long as a transit can ever take. The next one to be wholly visible in the United States will take place November 14, 1953. Transits of Mercury always fall in May or in November.

So far as we know, Mercury has no moon. In fact, certain astronomers have believed that Mercury himself was once a moon, dancing attendance on the now moonless

This is the planet Venus, the brightest object in the heavens after the sun and the moon. Because she is usually wrapped in clouds, astronomers seldom have a chance to see the lines on her face, and when they do, the markings are not nearly so clear as is shown here. Depending upon where Venus is in relation to us and to the sun, we see her in various phases, just as we see the moon. Those phases are shown beside the large picture of the planet. And at the extreme right is a sketch of what one seems to see when Venus passes between us and the sun. Here she is shown at the beginning of her journey across his disk.

planet Venus. But on Mercury the sun is magnificent and terrible. For at its nearest it would look more than ten times as large as it does to us on earth; and the heat would rise at times as high as 770 degrees Fahrenheit. Such a temperature would make an ocean boil and would melt tin and lead. But only half of Mercury can feel it; for his back is always turned away, and he must shiver in a cold hundreds of degrees below zero. It is hard to think that any kind of thing can live in such extremes.

Has Mercury an Atmosphere?

The telescope shows us faint markings on Mercury. They suggest mountain chains or outlines of land areas, but we do not know what they are. As to an atmosphere, no one can tell for certain, but any Mercury has must be exceedingly thin, for when the planet is in transit across the sun there is no sign of one. Even quite a thin one would then be evident, for it would bend the rays of light as the planet passes the edge of the sun's disk and we should see a bright rim along the planet's edge that lies outside the sun.

But more than this, Mercury and the moon, which is airless, reflect about the same percentage of the light they receive from the sun—that is to say, seven percent, which is not high. Planets with an atmosphere shine much more brightly. They have, as we say, a higher albedo (ăl-bē'dō)—for that Spanish word for "whiteness" is used to indicate the ratio between the amount of sunlight a spherical body receives and the amount it reflects. The earth, for instance, must have an albedo of over fifty percent.

Mercury may once have had a denser atmosphere. But some of it may well have escaped into outer space, and a great deal, if not all, of what remained must have found its way to the planet's cold dark side and have frozen solid there.

All the planets except the earth bear the names of Greek gods. The swiftest of them is fittingly named for Mercury, whose winged sandals carried him with unimaginable speed on errands for the other deities that lived on Mount Olympus.

The Jewel of the Heavens

The name given the planet Venus was also a happy choice. For Venus was the goddess of beauty and love and laughter. According to one story she sprang from the foam of the sea, though another made her the daughter of Jupiter and Dione (dī-ō'nē). The ocean nymphs discovered her and bore her down to their coral caves, where they tenderly nursed her and cradled her on a great blue wave. But when she was of an age to be presented to the gods, they set her adrift on the sea to be wafted to the

island of Cyprus. There she was met by gods and goddesses and conducted to her waiting throne on Mount Olympus, where she was beloved of all the gods and goddesses and worshiped by all men.

So it is small wonder that the most brilliant of all "stars" should have been named for her. For next to sun and moon, Venus is the brightest object in the sky. She is so brilliant that she can cast a shadow and is sometimes visible in broad daylight; but it is just before sunrise or just after sunset that she may be seen in her most dazzling splendor. Her albedo of fifty-nine percent is the highest in the solar system. But, like Mercury, she is not always visible. At times she appears as a crescent, which gradually changes to a half moon and finally becomes full, just as our moon does. This fact was discovered by Galileo (Găl'ĭ-lē'ō) as early as 1610. For when the great astronomer turned his first telescope upon her, he saw her pass through all the phases of our moon.

Photo by The Corporation of Manchester

John Crabtree, a merchant living near Manchester, in England, and Jeremiah Horrocks, his friend, were the first men who ever beheld a "transit of Venus"—that is, the passage of the planet between the earth and the sun. On a Sunday in November, 1639, when he knew that the transit ought to take place, Crabtree set up a mirror in such a position that the sun's rays should fall upon it; he was rewarded by the sight of a small black dot slipping across the image in the mirror. "Rapt in contemplation, he stood for some time motionless, scarcely trusting his own senses through excess of joy." This painting shows the event.

The Earth's Twin Planet

At times Venus is nearer us than any other planet, for then she is a mere 26,000,000 miles away. Unfortunately, she is such a tiny crescent at these times as to be almost invisible. Her distance from the sun is 67,200,000 miles, and her orbit (ŏr'bĭt)—or path—round him lies between our own and Mercury's. Venus and the earth are often called "twin planets," for the diameter of Venus is 7,700 miles, only some two hundred miles shorter than our own. But she is much nearer the sun and gets a good deal more heat and light than we do. She moves swiftly around her almost circular race course at a rate of nearly twenty-two miles a second. Because she is wrapped in a dense curtain of cloud that covers her surface we do not know the length of her day. But we do know that she revolves more than once during her 225-day year, for her dark side gives off heat—which it must get from the sun. Her atmosphere has a hundred times as much carbon dioxide as ours has, and since that is a gas which absorbs and retains heat her surface temperature must be very high—high enough to boil water. But so far no sign of oxygen has been discovered in her atmosphere and no sign of water vapor. So it would seem that she has little or no water. And if that is true she must be nothing but a reddish desert of fantastically carved out rocks and swirling sand—

For this god and goddess the planets Mars and Venus were named. The bright goddess of beauty was married to violent Mars, the god of war; and this painting shows us one of their many disputes.

sand constantly whipped up by the winds that are always sweeping her surface. For on Venus there must be a great difference between the temperatures of day and of night, and that difference in temperature would raise powerful, never resting winds

Venus has no moon, though scientists have at times thought they saw one. If she ever does get a glimpse of earth she finds us a beautiful sight, for when she is nearest us she would see our full disk, with our little moon, a tiny dot, swinging along beside us.

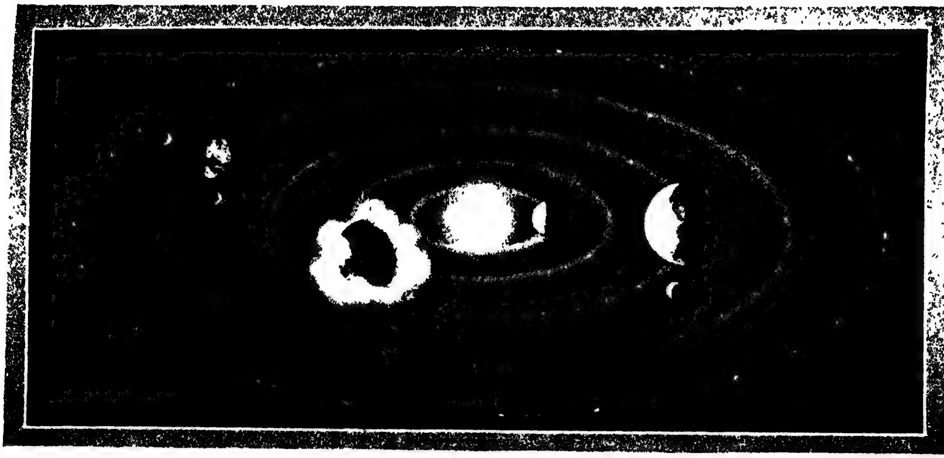
Once in a while, like Mercury, she passes right between us and the sun. At this time she looks like a small black patch upon the sun's bright face. Whenever a "transit of Venus" takes place, hundreds of telescopes are turned upon her in order that astronomers may test the accuracy of many of their measurements—especially of the sun's distance from the earth.

But they do not often have the chance. The event last took place in 1882. Many who are now reading these words will have a chance to see it in 2004 and 2012. Usually we have a pair of her transits in a century—always in June or in December—but in the present century none are scheduled.

Mars, the Ruddy Planet

Jupiter and Juno had a son who has fallen into very bad repute, because he fostered so much strife and suffering. For Mars was the god of war. To him the din of battle was sweeter than any other music, and gentleness and kindness were unwelcome to his fierce, destructive soul. People in all ages have feared him, and at mention of his name the whole world shudders.

He was represented as clad in gleaming armor, a plumed helmet on his head, a spear in one hand, and a shield in the other; and for attendants he had Eris, or Discord; Phobos, or Alarm; Metus, or Fear; Deimos, or Dread; and Pallor, or Terror. Red was the color for the battle ensigns of the ancient Greeks, and it was not unnatural for the ruby planet to be named after the god of war.



The diagram above shows the sun with those of his children that lie nearest him. First comes little Mercury, then Venus, then our own earth with its moon, then Mars with his two little moons, Deimos and Phobos, and last of all the tiny planetoids, strung like little beads each one upon its own separate orbit.

Next to Venus, Mars is the nearest of all planets to the earth; his path around the sun lies just outside our own, and at times he is only 35,000,000 miles away from us. Once in two years he comes, as we say, "in opposition"; that is, he rises in the east when the sun is setting in the west, or sets when the sun is rising. At this time he is biggest and brightest at midnight, when, from the Northern Hemisphere, he is high in the heavens and due south. It is not difficult to study him, for, unlike Venus, he has few clouds in his atmosphere. As a result we know more about Mars than we do about any other planet.

A Year 687 Days Long

The Martian day is only forty-one minutes longer than our own, and its seasons are almost identical with ours, barring its greater length of year. For it takes the war god 687 of our days to make his circuit round the sun. The planet has no mountains, and three-fourths of it is covered with deserts that range in color from yellow to dark red. The other fourth consists of darker areas—certainly not lakes or seas—which change color with the seasons. At the poles are caps of ice and snow, probably a good deal less than a foot thick. They vanish in summer, when darker areas appear in the vicinity—probably vegetation that depends for water on the melting ice. For Mars does have water, though very little of it. Its clouds are mostly yellowish sand or dust storms, with an occasional thin mist of ice crystals near the poles.

Are There Men on Mars?

Is there life on Mars? For years scientists have debated this question and have given it every kind of answer. Mars does have an atmosphere, but one, we now know, that is too thin to support man or any animal life of the kind we know. At noon the temperature is 50° F. at the equator 72° in the dark areas -but at sundown it sinks to 10°, and the nights must be bitterly cold.

In 1877 an Italian astronomer named Schiaparelli (skyä′pä-rĕl′lē), looking through a powerful telescope, saw certain narrow markings on the surface of Mars. They looked to him like great channels. In his description of them—written in Italian and telegraphed to Greenwich, England—he called them "canali," which means simply "channels." But an Englishman, translating the description, mistook the meaning of "canali" and called them "canals." There was no catching up with the mistake. People jumped to the conclusion that since canals are made by man, there must be men more or less like us on Mars to have made the canals there.

An American astronomer, Percival Lowell (1855–1916), who studied Mars through a very strong telescope at a great height in Arizona, also came to believe in the existence of the canals, and had many followers. But other observers could not find them and no one knew for certain whether they existed or not. Then, in July, 1939, Dr. Edison Pettit of the Mount Wilson and Palomar observatories was one night looking at Mars through a small telescope in his backyard in Pasadena, California. He was studying the planet's changes of color. Suddenly a canal appeared, and then another—and another and another. By the end of the year he had seen forty. No longer could anyone doubt their existence.

What they are we do not know though they still are called "canals." They must be some fifty miles wide and they go quite straight. Some day when space ships travel to Mars we may find out more about them. Meanwhile we may be sure that no men live on the planet.

If you could stand on Phobos, one of the tiny moons of Mars, that planet would probably look about like this to you if you were looking at it in its crescent stage. You would certainly have a clear view of the "canals"—and you might even be able to find out what they are.

Queer Moons That Attend Mars

To the Martians our old earth would be the queen of stars, a jewel in their sky at dawn and dusk much as Venus is in ours. But the sun would seem much smaller than to us. Three times a day a little moon, perhaps some ten miles through and only 3,700 miles away from Mars, would go galloping round the planet—a funny little fellow that in the evening would be seen as a tiny crescent rising—of all places—in the west, and some four hours later would have grown to be a bright full moon. This little inner moon, which is called Phobos (fō'bŏs), and his still tinier brother Deimos (dī'mŏs) were discovered in 1877 by Asaph Hall (1829–1907), who named them for the war god's sons. Deimos is perhaps not more than five miles in diameter, the smallest moon in all the solar system, but he is only 12,500 miles away from Mars and like his brother is a speedy little fellow who makes the circle round his ferocious parent in 132 hours. A boy could jump half a mile into the air on little Deimos and would need five minutes to come down again; and a man who on our own globe weighed 150 pounds, on Deimos would not weigh more than a quarter of a pound.

A person of lively imagination can plan amazing sports to take place on a little moon like this. Professor F. R. Moulton describes the following game of baseball which a lonely boy could play with himself on Phobos, if only he had air to breathe.

"Our one-man team would first take the position of pitcher and throw the ball horizontally. The ball would go all the way around the moon. He would then have time to get a bat and strike at it. If he missed it he could take his three strikes, then put on his mask, gloves, and chest protector, and catch himself out when the ball came around the fourth time.

"In case he hit the ball, and it bounded, he could play the part of an infielder by picking the ball up as it came bounding around the moon. He then could throw to first and catch himself out on the base as the ball came around again. If he hit a

fly in place of a grounder, he might draw on his glove and, playing the part of the center-fielder, catch himself out. A strong batter might make a home run."

Making a New Moon for Mars

The last sentence sounds tame enough, but it means that the batter could knock the ball right off the moon, so that it could never come back but would start out on a career of its own as a little moon to Mars.

All this is just a joke, if you like. But it is all absolutely true, just the same; and if we could ever live a while on little Phobos, we could play ball just like that.

This is what certain astronomers say they can see on the planet Mars. Since the "canals" are too faint to be photographed, each observer must draw what he sees. The straightness of the lines has led people in the past to think they represented canals dug by living creatures. But we know that Mars could not now support animal life.

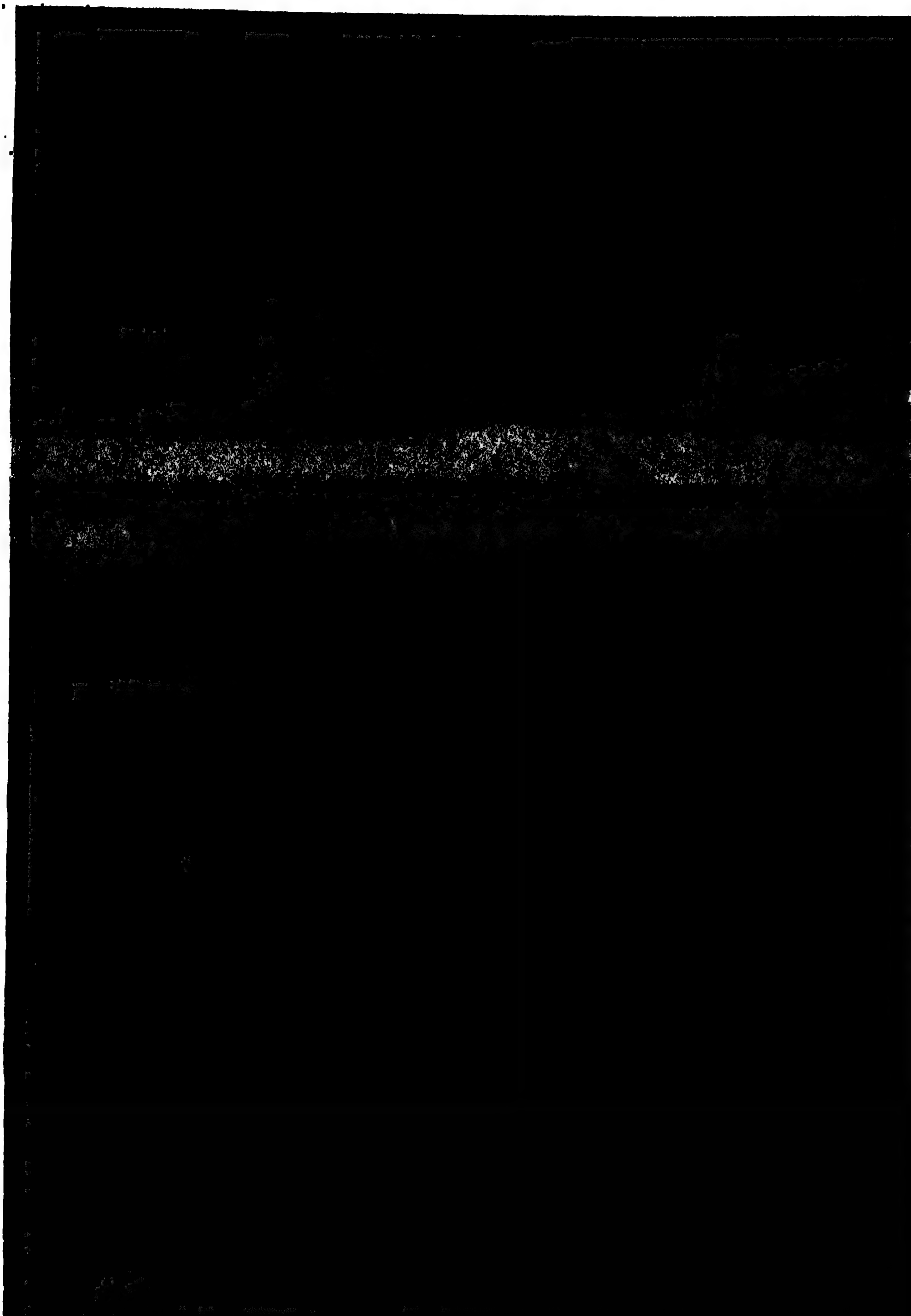
For many years, and especially since the invention of wireless, it has been the dream of man to communicate with Mars. Indeed, various attempts have been made to do so, but so far there has never been an answer—perhaps that may be because a Martian has never yet been born.

Mercury, Venus, the earth, and Mars are fairly close together; but between Mars and Jupiter, the planet whose path around the sun lies next outside that of Mars, there stretch 300,000,000 miles of space. For centuries astronomers believed that this was empty, but now we know that it contains a group of hundreds—or probably of many thousands—of very tiny planets known as "planetoids" (plăn′ĕt-oid) or "asteroids" (ăs′tēr-oid). These "minor planets" travel round the sun each in its own orbit, and are suspected to be all that remains of a great "major planet" that once met with some stupendous accident.

There is an interesting story about the discovery of these pigmy worlds. For many years learned men had suspected that there was a planet traveling around the sun between Mars and Jupiter. Finally a German astronomer, Baron von Zach (fôn tsäK), began to conduct a thorough search for it. He appointed twenty-four astronomers, at different places in Europe, who were to rake the heavens in an effort to find the little wanderer. But in spite of all their care the tiny truant slipped between the fingers of these armed policemen—only to fall into the clutches of a man who was not thinking of capturing a baby planet at all. For while an astromoner named Piazzi (pyät′sē) was one night making a map of the stars at Palermo, in Sicily, he saw the little fellow through his telescope. This happened on the first night of the nineteenth century—January 1, 1801. He immediately sped the news to Germany, but in those days communication was so slow that by the time the word reached there the planet had escaped again. It was about a year before it was picked up once more.

Hundreds of Little Worlds

In honor of the place of its discovery the little world was named for Ceres (sē′rēz), the patron goddess of Sicily. But since that time it has had to share honors with hundreds of other similar little spheres. In fact, they have become so numerous that they are known by number instead of by name—and the more there are discovered, the smaller they become. Ceres measures four or five hundred miles across, but of all the hundreds of its companions only a dozen or so can boast of a diameter of more than a hundred miles and probably most of them are from ten to fifty miles through. One has a diameter of less than a mile.



From a painting by Chesley Bonestell for the book THE CONQUEST OF SPACE, by Chesley Bonestell and Willy Ley, published by The Viking Press (c) C B 1947

To future space travelers Mars may well show scenes much like this one, with worn-down mountains on the horizon, a canal this side of them, and a wide expanse of desert swept by dust storms. But there probably will be green areas, too, like the one on the weather-worn hillside in the foreground.

Reading Unit No. 7

A TRIP TO THE GIANT WORLDS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Why is Jupiter called the "king of the heavens"? 1–154-55

On which planet is the year 120 days long? 1–154

Name a planet that is sheathed in ice thousands upon thousands of miles deep. 1–154-55

What is the speed of light? 1–155

Who discovered the rings of Saturn? 1–156-57

Which planet has a moon nearly as large as Mercury? 1–156-57

Which planet rolls along its orbit like a marble? 1–158

Which is the most recently discovered planet? 1–159

Things to Think About

How did Roemer use the moons of Jupiter to calculate the speed of light?

Why are the rings of Saturn sometimes invisible?

How does gravitation affect the orbit of the planet Uranus?

Why is a day on Saturn only ten and a fourth hours long?

Picture Hunt

How many earths would it take to reach across Jupiter's diameter? 1–155

How does the earth compare in size with Saturn's outer ring? 1–158

Related Material

Why did the Greeks call Jupiter the king of the Gods? 1–154

How is the speed of light measured to-day? 1–417

What do scientists believe as to the way in which light travels? 1–428

Who explained what the rings of Saturn were? 13–377

What is Saturn's position in the solar system? 1–106

How was the planet Uranus discovered? 1–157-58, 13–404

Leisure-time Activities

PROJECT NO. 1: Using a marble and a ball of proper size, demonstrate the relative diameters of Jupiter and the earth, 1–155.

PROJECT NO. 2: Using a ball and cardboard make a model of Saturn and its rings, 1–156.

Summary Statement

The planets farthest from the sun are Jupiter, Saturn, Uranus, Neptune, and Pluto. All but Pluto are of enormous size.

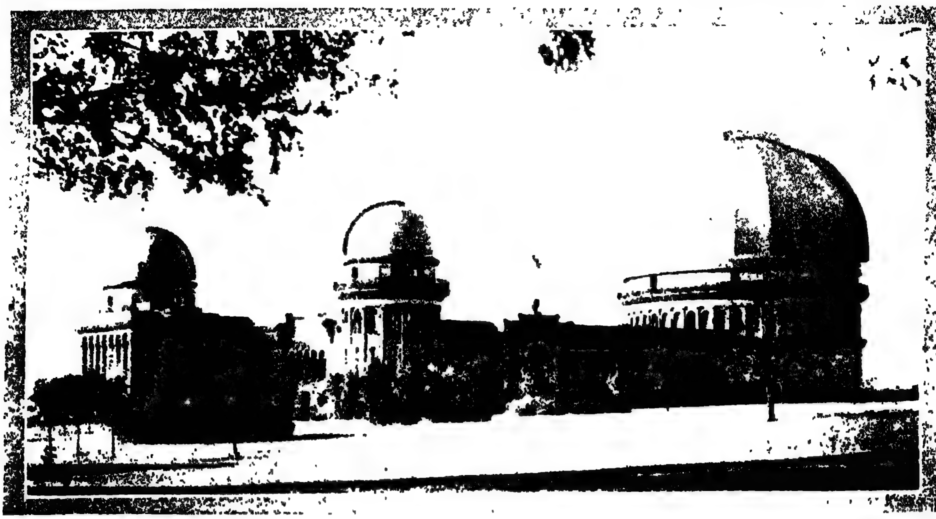


Photo by Yerkes Observatory

The Yerkes (yûr'kēz) Observatory, shown above, is one of the finest in the country. It belongs to the University of Chicago, though it is situated at Williams Bay, Wisconsin, where the air is clearer.

A TRIP *to the* GIANT WORLDS

Vast Planets So Far Out in Space That Their Noon Is a Dim Twilight and Their Year May Last a Century or Two

JUPITER was king of the gods. They were an unruly lot, but he kept them more or less in hand and ran the world as well. His home was on the top of Mount Olympus, a beautiful spacious place where all the greater gods lived in dazzling splendor. From that seat of power they were long ago cast out by man's ever-growing knowledge, but high in the heavens Jupiter still reigns as a planet in the evening sky, sometimes rivaling the splendor of Venus. For once in every thirteen months he is "in opposition"; that is, he rises in the east just as the sun is setting, and then as he mounts the sky he grows brighter and brighter until midnight. You cannot miss him then, for he is indeed king of the heavens.

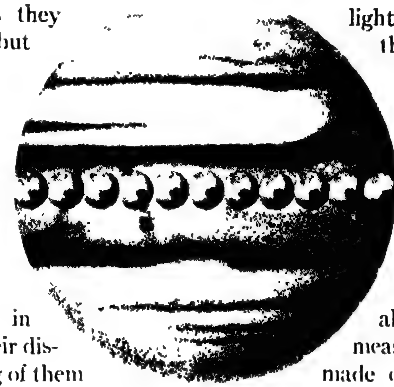
In size he is stupendous. If all the other planets were lumped into one, he would still be two and a half times larger than the body they would form. The combined surface of twelve hundred globes, each the size of the earth, would not be enough to provide him with a "skin." In diameter he measures 86,700 miles, and he averages 483,000,000 miles in distance from the sun. He gets only one twenty-seventh of the light and heat that we get. You will not be surprised that, since he is so far from the sun, he takes a long, long time to travel round it; you or I would have to be 120 years old, as measured here on earth, before we could celebrate our tenth birthday on Jupiter. His year is equal to nearly twelve of ours. But if his year is long, his day is short—a little less than ten hours with five hours of daylight and five of dark. This means that he must spin, at his equator, nearly thirty times as fast as the earth does.

We are sure that this greatest of all worlds is uninhabited. He is so far from the sun that he gets very little heat from it. Then, too, he is covered by a dense layer of clouds made up of methane (mĕth'ān) gas and ammonia crystals. They float on an atmosphere of hydrogen. The body of the planet—probably solid rock and metal—is sheathed in a layer of ice thousands upon

thousands of miles thick. For Jupiter's temperature is 210° below zero Fahrenheit.

Yet in all this frozen night disturbances occur—"storms," "eruptions." They may be chemical explosions—of hydrogen perhaps. Or they may be actual volcanoes.

As is befitting such a royal planet, Jupiter has no less than eleven attendant moons, two of them bigger than the planet Mercury and two others only some fifteen miles through. Three of the moons are perversely traveling in the opposite direction from the rest. Perhaps they started life as asteroids but were seized in the gravitational arms of the great world and held forever captive. The four largest of these moons were first observed by Galileo and are sometimes called the "Medicean (mĕd'ĭ-sē'ăn) moons," after a famous Italian family who ruled in Florence at the time of their discovery. It was the finding of them that proved to the world that Copernicus had not gone crazy when he said that all the planets circle round the sun.



The great planet Jupiter is 88,700 miles in diameter. In other words, if you could string beads the size of our own earth on a gigantic cable and hold the necklace up against him, it would take eleven of the beads to reach across his diameter.

After the finding of the four large moons, a table was compiled to show when and where they could be seen and when they were due to disappear behind the planet or within its shadow. And then it was found that, for some reason which Galileo could not understand, the eclipses did not run on scheduled time. Sometimes they were eight minutes early and at other times eight minutes late.

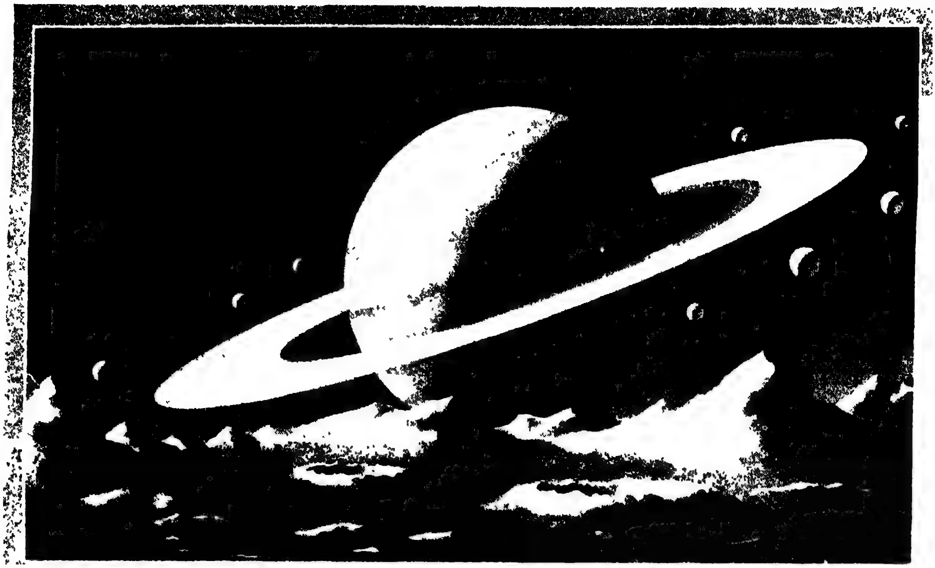
The great puzzle was solved by Ole Roemer (rē'mĕr), a Danish astronomer. He had an idea that it might take light—swift as light may seem—a certain time to get from one place to another. It had formerly been supposed to travel instantaneously, just as if it were everywhere at once. Now Roemer thought that possibly the reason why the moons of Jupiter were eight minutes late at one time and eight minutes early at another was that it would take the light sixteen minutes longer to get here from Jupiter when Jupiter was at his farthest from us than when he was at his nearest. And since Roemer knew the distance between the nearest and the farthest point, he had only to divide it by sixteen to find out the speed of light. So in 1675 he made his first rough estimate of 200,000 miles a second. It was the first time the speed of light—by far the swiftest thing we know—had ever been measured.

The discovery of the speed of light was of vast importance for the progress of science. To be sure we have now arrived at figures more exact than Roemer's; we know the speed of light is 186,300 miles a second. But without his discovery our modern sciences of physics and astronomy could not have come about. It gave us a better measure of the earth's orbit and made our predictions of eclipses more accurate. And all this because the far-off moons of Jupiter were not on time for their eclipses!

Old Father Time

We have all seen the old gray-bearded man who appears in almanacs carrying an old-fashioned scythe. "Old Father Time" we call him, but his proper name is Saturn. He was the son of Uranus and of his wife, the Earth. They once ruled the whole world until this son deposed his parents and became the father of Jupiter, by whom he was in turn deposed—though not before he had eaten several of his own children! For Saturn, you see, was really "Time," which sooner or later destroys whatever it creates.

But though his reputation was so shameful, the old god had the most interesting planet in all the solar system named for him. It is not very beautiful to the unaided eye. Indeed, to the ancients the dim, yellowish fellow was decidedly unlucky, and anyone who happened to be born under



Let us suppose that you could take your stand on one of the planet Saturn's nine moons. Your view of him, with his triple ring and his other eight moons, would be a good deal like the picture above.

his influence was expected to be dull and disagreeable. But early in the seventeenth century, the famous Galileo turned the magic glass of his new invention toward the gloomy planet, and, behold!—there was a body totally unlike any other in the sky. It must have been an exciting moment for the great astronomer.

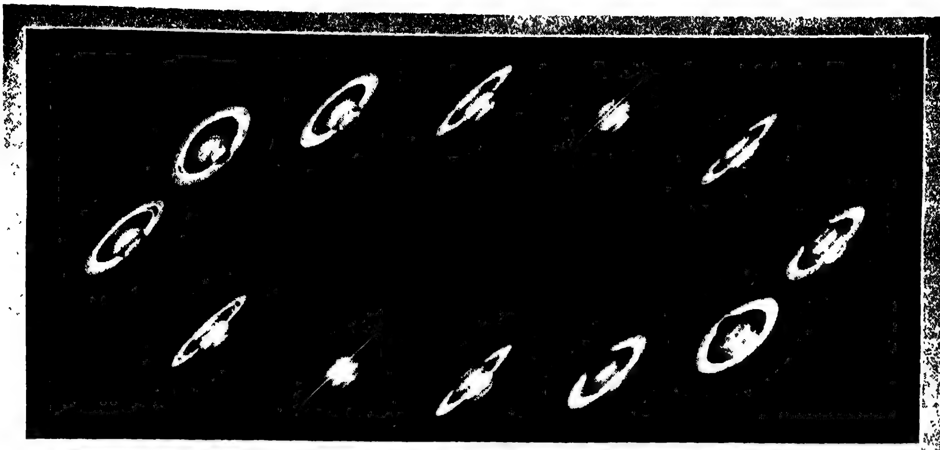
What Galileo Saw

What he saw was a planet seven hundred times larger than the earth and girdled with an enormous belt. We now know that the belt consists of three broad, flat rings, one inside another, floating in space, and not attached to the planet at all. The two outer rings are bright, and are separated by a dark space 3,000 miles broad. The inner ring is by no means so brilliant and is so filmy that sometimes we can see the body of the planet through it. All are very thin through; in fact, they cannot anywhere be more than ten miles thick. When they are tipped so that we look straight at the edge of them, they are almost invisible even through the most powerful telescope. But these thin whirling bands cover an area that is stupendous. The planet has a diameter of 71,500 miles, and the outermost ring is 171,000 miles across from outer edge to outer edge.

But what can these great wheels be made of? Only rather recently we have proved that they are composed of millions upon millions of particles of "star dust," like swarms of little meteors. The size of the particles we have no way of telling, but probably they are very small; and since they are scattered far apart, each one is virtually a tiny moon that goes wheeling round the great yellow planet. How amazing must be the sight of them any clear night on Saturn!

Nine Gay Moons

But Saturn has still other startling features besides his triple ring. He has nine gay moons whirling around him. The largest of them is Titan, even larger than the planet Mercury and the only moon in the whole solar system to have an atmosphere. That atmosphere contains a great deal of methane, or marsh gas. One of the smallest moons is Phoebe, a little globe that sails along high above Saturn's other moons but in the opposite direction from the rest. She takes



To the observer following Saturn through a telescope, he presents a series of phases, just as our moon does. **Depending on the angle one views him from, one sees the rings edgewise or from above or below.**

her time, too, for her journey covers eighteen months, while Mimas, the moon nearest Saturn, gets around in about twenty-three hours. One side of Japetus (jăp'ē-tŭs), a moon of moderate size, if for some reason five times as bright as the other side. A tenth moon was discovered but is now lost.

Less than a hundred years ago certain astronomers believed that Saturn was inhabited by beings like ourselves. Now we know it is impossible. For not only does he get very little light from the sun, but he also weighs the least of all the planets for his size he is so thin that he could not bear us up. Though he is seven hundred times larger than the earth, he is only ninety-five times heavier. He is so light that if there were an ocean large enough he would float in it like a cork.

Saturn is 880,000,000 miles away from the sun—so far that he can get very little light. His path around the sun is proportionately long; it takes him almost thirty of our years to get around. But though he is so large, he is exceedingly lively. He spins so fast that his day is only 10¼ hours long. In structure Jupiter, Saturn, and the planet next beyond them are about the same. All have atmospheres.

The planet is of amazing beauty when seen through the telescope. Around its equator is a bright golden-yellow belt, with gray on either side. Gray stripes shade into pink and yellow stripes over the rest of the surface until, near the poles, there is bright greenish blue, with dark gray capping the poles. The gorgeous ball is girdled by its whirling rings of grayish blue, with little moons strung like beads along the edge.

On a clear moonless night in late spring or early summer you may possibly be able to see a small pale-green light in the distant heavens, far above the horizon. The untrained eye would take it for a star. You must know exactly where to look and you must look very closely, for the faint waves of light have traveled twice 1,800,000,000 miles to get to you. First they went out this far from the sun to the distant planet, and then they were sent back about the same distance from the planet to you. No wonder they are dim they have traveled nearly four billion miles out and back.

Captured by the Telescope

Uranus (ū'rà-nŭs), for that is the planet's name, was quite unknown in ancient times, and even after the invention of the telescope was thought to be a star. But in 1781 Herschel (1738–1822), a star-loving German music teacher and organist who lived in England, discovered that the star was a very distant planet. At first he doubted the discovery, thinking he might have seen a comet; but the fact was finally established and the new world was first known as

"Herschel's planet." Later it was christened Uranus, after the father of Saturn. This was the first planet to be discovered through the telescope.

It lies so far away from its parent, the sun, that its temperature is 300° below zero. The sun must be only a glittering speck on the horizon—as Venus or Jupiter is to us. Because of that great distance the year is very long. Few of us there would ever see our first birthday, for the Uranian "year" is as long as eighty-four of our years. But a "day" would be extremely short—five hours toward the sun and five hours away. This means that Uranus must whirl very fast, for it has a diameter of 32,000 miles—four times greater than the earth's.

Its axis is tilted so far that the planet rolls along its orbit like a marble. About its surface we know nothing. There are five moons, moving, like Phoebe, in disregard of solar traffic rules.

This will give you some idea of the enormous size of the planet Saturn. If the earth could be placed on one of his outer rings, it would look about like this, for the ring is over ten thousand miles across.

For many years Uranus was believed to be the outermost of all the planets. But he did not behave quite as a planet should. From time to time he got a little off the track in his course around the sun. Finally a young Englishman named John Couch Adams (1819–1892), who was a student in Cambridge University, heard of these irregularities in the planet's motion. It occurred to him that the whole matter could be explained by supposing another planet still more distant, which by its gravitative pull might be disturbing Uranus In 1843 he set out to discover where such a planet might be found. But he did not rake the heavens with a telescope to search it out. Instead, he sat down with a pencil and for some two years he covered sheet after sheet of paper with his figures. When he was twenty-six he had solved the problem.

He made out a chart showing where the planet should be found, and took it to Sir George Airy (1801–1892), who was then Astronomer Royal at the Observatory in Greenwich, England. It was his hope that Airy would point the great telescope at the spot indicated and find the new world as predicted. But Airy did not recognize the value of the paper that was given him. He put it in his desk and left it there, much to young Adams's disappointment.

About a year later a French astronomer named Leverrier (lĕ-vĕ'-ryā'), who had been making calculations similar to those of Adams without knowing anything of Adams's work, announced to the world where the unknown planet could be found. Telescopes at Berlin at once began the search, with the result that the planet was seen in Berlin by F. G. Galle (1813–1910) on September 23, 1846. Airy at once announced that a similar prediction had been submitted to him by Adams. There was a great discussion as to who should have the credit for the discovery, though Leverrier himself had so little pride in it that during his whole life he never took the trouble to look at the planet through a telescope. We now give the honor to both. In later years the two brilliant mathematicians met and became lifelong friends.

Neptune, God of the Sea

The new world was named for Neptune, whom the ancients had worshiped as the god of the sea. He was a majestic personage, with flowing hair and beard, a forked spear in his hand, and a crown of seaweed on his head. From his coral caves he could stir up or quell the wildest storm or send an earthquake. His namesake is by no means so terrible. We cannot see the planet with the naked eye; in fact it is so far away that even with the strongest telescopes we can learn nothing about its surface. But we

know that it receives only $\frac{1}{900}$ as much sunlight as we do, and that its diameter is 31,000 miles. We can tell, too, that it has two moons. One travels backward, in exactly the opposite direction from the one that our moon pursues.

Pluto, the Outermost Sentinel

There are plenty of surprises still left in astronomy. We may still wake up in the morning to find that a new planet has been discovered the night before! That is what happened one morning in 1930; though, to be sure, the new planet then announced had been predicted fifteen years before.

Back in 1902 Professor Percival Lowell had said that there must be another planet out in space beyond Neptune to account for the queer action of Uranus, and in 1915 he told us that it would be found at one of two possible points in opposite corners of the sky. When he died the next year, he left money to carry on the search in the great observatory he had built at Flagstaff, Arizona. Not until January, 1930, was his planet found—just where he said it would be! If you wonder why it was not seen sooner, the answer is that it is as hard to see as a candle 4,000 miles away would be. Its light has to travel thirty-six hours at the rate of 186,300 miles a second before it reaches us, for the little world is some 3,670 million miles away. Its time of circuit around the sun is over 248 years long, and it can see the sun only as we see some of the distant stars as a shining pinpoint of light. It is smaller than the earth, and, curiously, is a good deal denser. Because its orbit is very unlike that of the other worlds certain scientists think there may be still another planet as yet undiscovered.

The new planet was fittingly named for Pluto, god of darkness and of death. For out in the realm of night where the new world swings there is no genial sun, no warmth of spring and summer to nourish life.

This is the mighty god for whom the planet Neptune was named. He was brother of Jupiter and Pluto, and ruled all the waters of the earth. He lashed up the sea with his three-pronged spear, and when he smote the rocks, fountains and horses sprang forth.

Reading Unit No. 8

VAGABONDS OF THE SKY

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is a comet? 1–161-63

Which is the most famous of all comets? 1–163-64

About how many meteors fall on the earth each day? 1–165

Which is the largest meteorite ever found? 1–165-66

What metals are found in meteors? 1–167

Do meteors ever contain diamonds? 1–167

How may meteors produce beautiful sunsets? 1–167

Things to Think About

Does the earth's atmosphere help to give a meteor its light?

Is there danger to life and property from the many meteors that fall to earth each day?

How may meteors change certain surface conditions of the earth?

Why are meteors pitted and pierced with small holes?

Picture Hunt

Why is the sky sometimes ablaze with meteors? 1–162

When does a meteor begin to burn? 1–164

Related Material

How have meteors affected life on the earth? 1–166

What is the origin of the dust in space? 1–117, 220, 377

Does friction explain the light from "shooting stars"? 1–320-21

Why is air needed for the combustion of meteors? 1–384-85

How may friction produce heat? 1–320, 382

What is the hardest substance found in meteors? 1–167, 9-422

Practical Applications

How has iron in meteors been used? 1–167

Why are meteoric diamonds useless? 1–167

Leisure-time Activities

PROJECT NO. 1: Collect and mount examples of earth substances found in meteors, 1–167.

PROJECT NO. 2: Make clay models of well-known meteors, 1–161, 165, 166.

Summary Statement

Meteors are metallic in substance. They are attracted from space by the pull of the earth. Some believe that they become very hot and start to burn as they fall through the air which surrounds the earth.

Photo by American Museum of Natural History

This is the famous Willamette meteorite, the largest ever found in the United States. It was discovered near Portland, Oregon, in 1902, and is now in the American Museum of Natural History in New York City. It is ten feet long and weighs fifteen and a half tons. The deep pits shown here were caused by rusting as the great mass of metal lay in the ground. On the other side of it are smaller holes burned out as it hurtled through the air. For the force of the blast gouges great pits in a meteorite.

VAGABONDS *of the* SKY

Star Tramps That Dash In and Out among the Solemn Planets and Make a Loop around the Sun

SOMETIME you may have a chance to look up in the sky and see a huge, bright ball with a long, spreading tail that will be crossing the heavens for a few weeks and will then vanish. In olden days there was no accounting for such mysterious visitors. And because there was no accounting for them, ignorance and superstition soon wove horrid fears about them. These scapegoats of the sky were credited with bringing every known disaster to the human race; wars, famines, plagues, floods, and convulsions of the state were said to come in their train.

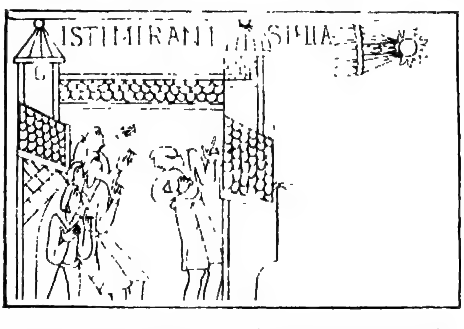
Yet comets are about the most harmless objects in the sky—and this in spite of the fact that they are very large. For astronomers tell us that the tails of certain comets are hundreds of millions of miles in length, while their heads are many times larger than the earth. If ever we did run into one of them, what a collision it would be! For a comet may reach the terrific speed of three hundred miles a second, or 18,000 miles a minute. It is a fact that the earth has at times—as in 1861—passed through a comet's tail, but no one was the wiser until it was all over. There had been a harmless shower of meteors, and that was all. As for an actual collision! The chances of it are about as good as the chance that if we closed our eyes and fired a gun at random into the air we should bring down a bird of paradise.

Even after centuries of study, we still find these tramps of the sky mysterious in many ways. For one thing, we are not quite sure what comets are made of. The word itself is from the Greek and means

At certain times of the year the night skies are sure to be ablaze with meteors. Astronomers think that this is caused by the fact that the earth, as she swings around in her orbit, at those seasons crosses the orbit of a swarm of meteors. The diagram above will make this clear. In it the earth is traveling on her circular path near the sun, while the meteors are traveling along the much larger oval course.

"long-haired," not an inappropriate description of the long bright locks that stream away from the body's "head." The head seems to consist of a bright, solid body called the "nucleus" (nū′klē-ŭs)—which is the Latin word for "kernel"—surrounded by a veil or shining mist, the "coma" (kō′mȧ) from a Greek word meaning "hair."

The coma gradually shades off into the comet's tail, a thin, transparent veil that streams behind it much as smoke does from a swift locomotive—except that when a comet nears the sun its tail always gets very much longer and always points in a direction away from the sun, no matter which way the comet may be going. The reason for this is not very clear, but it is thought that the little particles of "star dust"—the specks of solid stuff that make up the comet's tail—are driven away from the sun by the force of its light waves. This force is known as the "mechanical pressure of light," and very tiny bodies are unable to resist it.



On the famous Bayeux (bī′û′) tapestries, which the queen of William the Conqueror made with the help of her ladies to commemorate the conquest of England in 1066, you will see embroidered the quaint picture shown here. The strange tailed object in the upper right-hand corner is nothing less than Halley's comet, which made one of its rare visits to our skies in that important year.

Many comets go very near the sun—so close, indeed, that they would certainly fall into it if they were not traveling at such terrific speed that before the sun has time to grab them they have shot around it. For they cannot just pass it by. They circle round it at close quarters, like a yacht rounding a buoy in a race, and then dash off again upon their long, long journey into space.

Often they come back, but in many cases it is doubtful if they ever do. For a comet's orbit is never circular, as a planet's tends to be. It is either a very long ellipse (ĕ-lĭps′)—which means that its shape is like a very long, thin football—or else it is what we know as a parabola (pȧ-răb′ō-lȧ)—a hairpin curve whose lines, no matter how far they may be extended, can never curve back upon themselves and meet again. A comet traveling in an ellipse is sure to come back some day if nothing happens to it, though its return may be a very long time off. One observed about the

time Napoleon was born is estimated to require two thousand years to finish its voyage through the cold, dark depths of space.

But a comet whose path around the sun is a parabola is lost forever. Where the starry tramps may go no one can say. Many astronomers believe they leave our solar system altogether and go traveling on to other suns across the universe. As a rule, the greatest comets never come back. Sometimes, however, a comet may be firmly grasped by a large planet, such as Jupiter, who may hold the wanderer back and send him whizzing within the limits of the solar system—that is to say, within the sun's relentless hold.

This is the most famous of all comets, named for Edmund Halley, the man who first predicted its return. The head is clear enough, but only part of the long tail is shown in the picture. The short white lines in the background of the photograph are the images of stars, as they traveled by during the long exposure.

The End of a Comet

Comets that pay a regular visit to the sun may be described as falling round and round him. Because of his tremendous gravitational pull, they put on their greatest speed as they approach him and are able to dash by. They whirl around him—like a ball at the end of a short string—and then dash off again along their lengthy orbits. But as they retreat, their speed grows less and less until they are barely moving. At that point the sun exerts his authority over his wayward offspring and drags them home, falling at ever-increasing speed toward their relentless parent, whose light they reflect.

This career can never end until the comet at last breaks up. For to go to pieces is probably the fate of every one of them. Their thin gas and little solid fragments—made, as we know, of the same stuff as stars and planets—will be torn apart by the gigantic gravitational forces of which they are now the toys.

There are a great many starry vagabonds. Astronomers have recorded about a thousand comets altogether; and one scientist has said that there are "as many comets in the sky as there are fish in the ocean." Learned men are able to foretell the return of many of those that move in an ellipse—or are, as we say, "periodic." Whenever their visits can be predicted, comets are said to be "expected," in contrast with those that are known as "unexpected."

Halley's Comet

Of the periodic comets some are very famous. Encke's is well known, for the sun brings him dashing back every three and a third years. But the most famous comet of all time is the one that bears the name of Edmund Halley (1656–1742), an English astronomer and mathematician, who

This is what happens to a meteor as it travels through the earth's atmosphere. At the top of the picture it is shown as a great lump of stone or metal moving swiftly through space but already near enough to the earth to feel the force of gravity. So it is drawn toward us, and finally plunges into our atmosphere, where it is speedily heated white-hot by the friction of its passage through the air. Sometimes the meteor is quite burned up before it ever reaches the earth—it is one of the "shooting stars" that you may see in the skies on any clear night. At other times it plunges on toward the earth until its mass breaks up with a loud explosion and falls to earth as a shower of meteorites, which may be no larger than grains of sand or may weigh many tons. If you should ever be lucky enough to see a meteor actually come to earth, do not run to it and pick it up without first seeing how hot it is. It may be very hot indeed from its long journey—and on the other hand it may be so cold that frost will form on it almost at once. This is because the meteor, before it entered the earth's air, was colder than any temperature we ever find on earth, and if, as the outside of it melted, the molten or gaseous particles were instantly swept away by the swift rush of air, its cold inside would still be exposed, for there would not have been time for the meteorite to become heated through.

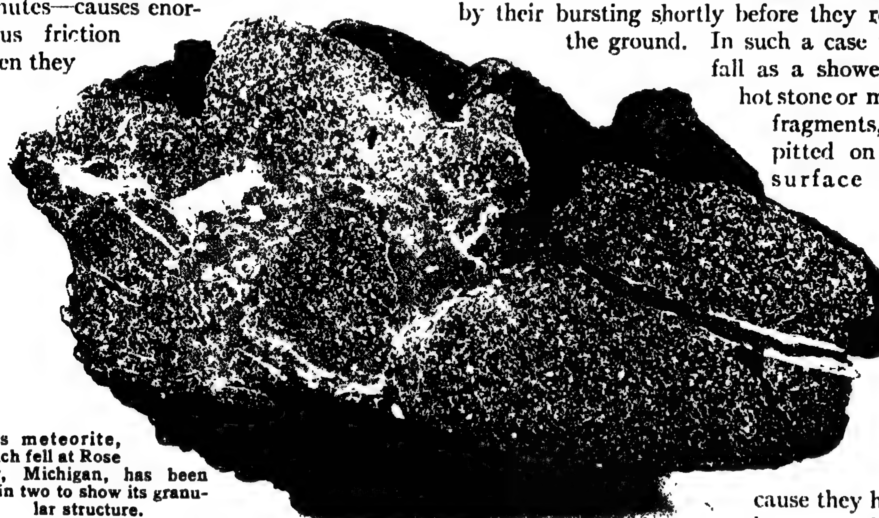
was a close friend to Sir Isaac Newton. When a brilliant comet appeared in 1682, Halley and Newton discovered that its orbit was the same as those of comets which had appeared in 1531 and 1607. Halley concluded that all three must be the same comet, coming at regular intervals to pay its visit to the sun. Immediately, with splendid courage, he foretold its return in 1758. He himself could never know whether his prophecy came true, but at the time he set, the skies were watched by many eager eyes, in expectation of the visitor. And there he was on Christmas Eve, 1758—a punctual guest to keep his seventy-six-year-old appointment with the sun. Halley's prediction had not been just a foolish guess.

A careful search into old records and ancient Chinese chronicles has shown that every return but one of Halley's comet has been recorded as far back as the year 240 B.C. Its last appearance was in 1910. No one can tell how many centuries it will keep up its flaming journey before it is finally wrecked and vanishes into the eternal night of space.

What Are Falling Stars?

Falling stars, we call them—those little flaming specks that shoot downward through the heavens on any starry night. But if, by any unimaginable accident, a star were actually to fall, what a terrible convulsion there would be! The whole fabric of the

universe would be rent apart. What we see, then, cannot be stars at all. Instead, they are tiny fragments of a comet, or loose "dust" from the vast depths of space, which, coming within reach of the earth's arms of gravitation, are swiftly drawn into our atmosphere. There the terrific speed with which they travel—sometimes so great that they could encircle the earth in twenty minutes—causes enormous friction when they come in contact with our air. For even seventy-five or eighty miles above the earth the atmosphere is dense enough to offer great resistance to an object traveling at such a rate.



This meteorite, which fell at Rose City, Michigan, has been cut in two to show its granular structure.

Photo by American Museum of Natural History

Now friction, as you know, is but another name for rubbing, and when a thing is violently rubbed it is sure to grow hot. Savages sometimes start a fire by rubbing two pieces of wood together very hard. So you can imagine the heat created when an object traveling from ten to sixty miles a second comes in contact with the air. Its surface grows white-hot and finally turns liquid. For an instant there is a bright streak in the sky, and then the thing vanishes. Its ashes finally reach the earth as very fine dust.

Ten Million Meteors Every Day

We call these heavenly rockets "meteors" (mē′tē-ŏr)—from a Greek word meaning "high in the air." It has been estimated that at least ten million of them enter our atmosphere every day. The earth would be a dangerous place indeed if it did not have atmosphere to burn them up. Most of them weigh only an ounce or two, and some that we can see may be no bigger than a large grain of sand; but others are so great that they reach the earth before they can burn up. Often there is a loud explosion caused by their bursting shortly before they reach the ground. In such a case they fall as a shower of hot stone or metal fragments, all pitted on the surface because they have been so hot. But more rarely a meteorite—for such is its name after it has reached the ground—is very large, and plows a deep hole in the earth where it lands.

The Largest Meteorite in Captivity

Of course, the majority of meteors plunge into the ocean, but many have been found on land, especially in Mexico. The ancients believed that in an angry mood Jupiter had hurled them down at men. Later, men of science came to believe that they had not fallen from the sky at all. But finally the truth was forced upon them when in 1805 hundreds of peasants at a little town in France actually saw a shower of meteors reach the ground. In 1894, Lieutenant Peary found in Greenland a huge meteorite measuring 5 by 7 by 11 feet and weighing 36½ tons. The Eskimos believed it had been hurled to earth by evil spirits, but for many years they had used it as the source of supply for all the iron they had. Known

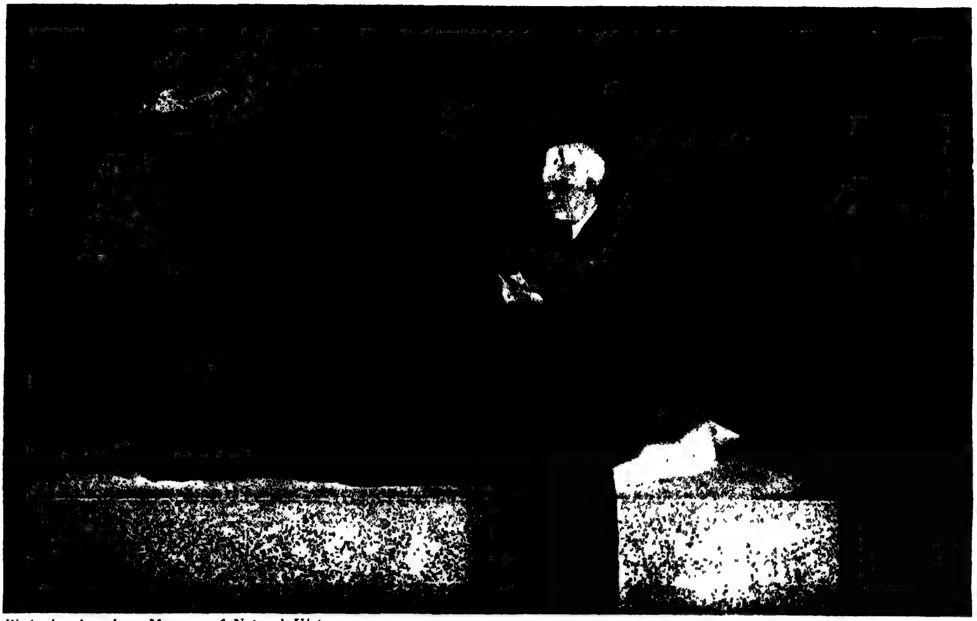


Photo by American Museum of Natural History

This is the largest meteorite in any museum. It weighs 36½ tons, and was brought from Greenland by Admiral Peary in 1897. The Eskimos always called it "the Tent," but when Admiral Peary's little daughter Marie Ahnighito Peary was a year old she christened the great meteorite "Ahnighito."

as "The Tent," it now rests in the American Museum of Natural History in New York City—the largest meteorite "in captivity."

One of the largest of known meteors struck the earth in the desert of northeast Arizona, probably more than a thousand years ago. It landed with such force that it left a hole six hundred feet deep and four thousand feet across, with walls that rise 150 feet above the surface of the earth. Many thousands of iron meteorites, thrown off by its explosion, have been found within a few miles of the place, and here and there a diamond—a jewel formed in the dark depths of heaven.

The Largest Meteor of All

An even greater meteorite has lately fallen in Siberia. So huge it is that had it happened to alight on a great city like New York or London, few, if any, of the millions of inhabitants would be alive to-day. Still more recently a wandering tribe of native Siberians reported the fall of a meteorite that killed 130 reindeer and plunged so deep into the frozen earth that a small lake appeared where it had landed. Others weighing not less than fifty tons have fallen in South Africa and Mexico.

"Sky Stones" That Proved Fatal

But in spite of all these rather terrifying tales, the chance that any one of us may ever be hit by a meteorite is very small indeed. In all the thousands of years in history there are very few such cases on record. It is true that in 1929 a meteorite eighteen inches in diameter fell into the midst of a wedding procession on its way to church in a little village in Yugoslavia. A man was killed and one of the women injured. The guests fled in all directions and the wedding was postponed. About a century ago a man in India was killed in the same way; and there is a record to the effect that in 600 B.C. a "sky stone" in China killed ten men and smashed several chariots. But these few cases form a very slender list, especially when spread through so many centuries.

The best evidence we have as to the origin of meteors was furnished by the breaking up and disappearance of Biela's (bē'lä) comet. For many years it had made its regular tour around the sun, and was always punctual in coming back. Then one time (1846) it dashed by in two sections. Clearly it had met with an accident. The next time it did not come at all; but just when it should have put in an appearance, the earth passed through an enormous swarm of meteors—undoubtedly pieces of Biela's comet which had been scattered through the heavens.

What Are Meteors Made Of?

All the meteorites that have been found are made of the same stuff we find in the earth's crust—rock materials and various metals, especially iron and nickel. As many as twenty-three such substances were found in a meteorite that fell in Australia; they included gold, copper, platinum, aluminum, and sulphur. Some three hundred years ago there lived in India an emperor who had a sword made of the iron found in a meteorite that had fallen in his empire. Most remarkable of all seems the fact that sometimes meteors contain diamonds, though such small ones that they can mostly be seen only through a microscope.

Sometimes meteors are so numerous that they seem to fall in showers especially during the months of January, April, August, and November. They are usually thickest between midnight and dawn. On November 12, 1833, a great meteoric storm occurred which lasted for nine hours. There were such swarms that many ignorant people were frightened into believing that the world was coming to an end. The spectacle was repeated on November 13, 1866. Astronomers now know that their "rain of fire," so startling at the time, was only the wreckage of what had once been a comet.

The November meteors are called the Leonids (lē'ō-nĭd), because they seem to fall from a group of stars called Leo—or the Lion. In the same way, the August showers are called the Perseids (pûr'sē-ĭd) because they seem to come from the star group known as Perseus.

How Meteors Make Our Sunsets

Most of the bodies in such showers never strike the earth. They are burned up while still in the air and float about as particles of dust, eventually to sink down to the earth and add their tiny bulk to its surface. And yet the total weight thus added amounts to something rather startling in a year. Much of the dust we see floating in the sunbeams comes from meteors. We should be grateful for it, since, by acting on the light waves passing through its tiny particles, it gives us brilliant sunsets. In the Tropics especially there are seasons of the year when these particles of dust form an exquisite ribbonlike belt of pearly radiance that arches upward from the sun and may be seen against a clear, dark, moonless sky before sunrise or after sunset. It is called the "zodiacal (zō-dī'ā-kăl) light." But it is never very easy to make out.

We have now traveled to the very edge of the sun's vast domain. Indeed, in tracking down the "wandering ghosts" we know as comets, we have journeyed way beyond the outermost planets into solar systems other than our own. It is these vast stretches which the farthest stars illumine that are now left for us to explore. In comparison with those distant suns, our own and all its little busy planets sink into insignificance. Our good old earth becomes a speck of dust and we ourselves shrink to microscopic atoms that live and breathe for an instant and then vanish forever.

Reading Unit No. 9

THE SUNS OF THE NIGHT

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is a star? 1–169-70
Where are there suns larger than our own? 1–170
Which star is as large as our entire solar system? 1–170
How are stars classified? 1–170
About how many stars are there? 1–171
What are the stars made of? 1–171
What is the difference between a planet and a star? 1–174-75

Things to Think About

How do we measure the distance from a star to the earth?
How do scientists determine the composition of the stars?
Why are the stars invisible in the daytime?
Why are there so few collisions in space?

Picture Hunt

What constellations are to be seen during the following seasons:
- southern-winter, 1–178A
- northern-winter, 1–178B
- southern-early spring, 1–178C
- northern-early spring, 1–178D
- southern-late spring, 1–178E
- northern-late spring, 1–178F
- southern-summer, 1–178G
- northern-summer, 1–178H
- southern-early autumn, 1–178I
- northern-early autumn, 1–178J
- southern-winter, 1–178K
- northern-winter, 1–178L

Related Material

How is the spectroscope used in determining what stars are made of? 1–187, 440-41
Who made the first accurate star maps? 13–404-5
How may the sun affect the light coming from a star? 1–427, 13–409
Do stars move through space? 1–114, 171
How may a motor be run by light? 1–414
What are some ancient Greek myths concerning the constellations? 14–425-32

Practical Applications

How is the constancy of the North Star's position useful to man? 1–170, 178
How is the parallax of a star used to determine its distance from the earth? 1–172-73

Leisure-time Activities

On a clear evening, locate the important constellations visible in the sky using the twelve star maps that follow 1–178.

It is very pleasant to imagine oneself swinging along through the evening sky in a comfortable seat on the crescent; but as a matter of fact, that pretty gleaming sickle would not afford even the thinnest edge on which a person could sit down. For as you know if you have read our story of the moon, the crescent has breadth but no thickness at all! It is nothing but a rim of light along the edge of a sphere as solid as our earth. And if you were seated on it, the stars that seem to be scattered all around it would look as far away as they do when you see them from your own window at home. You still would need to read this article to find out what they are like.

The SUNS *of the* NIGHT

So Far Away That They Seem Mere Dots of Light Are Billions of Huge Suns That Throw Out Heat through All the Universe

WHEN our early forefathers began to doubt that the stars were really the homes of gods, they naturally cast about to find some better way of accounting for them. A wise old Greek named Anaxagoras (ăn'ăk-săg'ō-răs), who lived in the fifth century before Christ and was put in prison for saying that the sun was not a god, hit upon the happy notion that the stars were red-hot stones. These, he thought, had long ago been cast up from the earth and at their lofty height had taken fire by reason of their swift rotation.

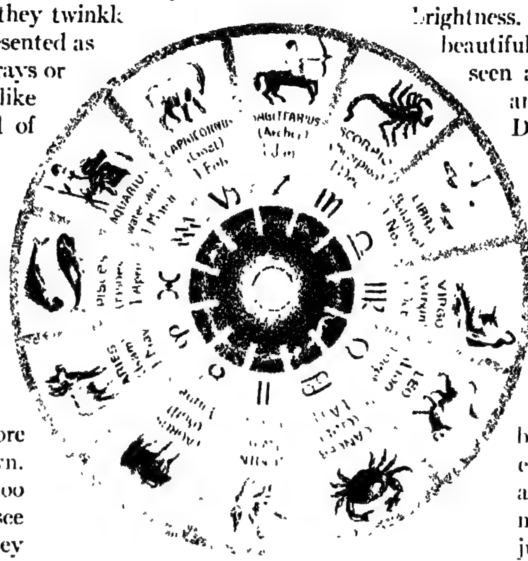
The followers of Pythagoras (pĭ-thăg'ō-răs), another ancient Greek philosopher, decided that the heavenly bodies could not fall because they all - the sun and moon, the earth, the stars and planets—were fixed to crystal globes which, one inside the other, continually revolved around a great central fire, from which the sun and moon got their light. There were ten of these great "spheres," and each one as it whirled gave out a musical tone—the inner and slower ones a low, deep note; the outer ones, notes higher up the scale. The outermost sphere of all, the one in which the fixed stars were set, gave off the highest note. And all these tones combined to form harmonies of such exquisite sweetness as man has never known. For man, according to the theory, has ears too dull to hear "the music of the spheres."

Ever since the days of ancient Greece, men have been constantly peering at the heavens, measuring and calculating and devising instruments, till now we can give a pretty definite answer when you ask, "What is a star?"

It is a body very much like our sun. It gives off heat and light, as does the sun, and it is made of just about the same ma-

terials. Some stars are very much larger than the sun, and some of them 300,000 times as bright; but they all consist of gases heated to an unbelievable degree. They do not look like suns because they are so very far away. They seem mere points of light; and because they twinkle they are often represented as having long bright rays or arms—more or less like a starfish. But all of them were formed as was our friend the sun, and all of them are sending heat and light out into millions of miles of chilly space. For all we know, they may be warming little whirling worlds more or less like our own. But they are much too far away for us to see their worlds, if they have any.

"One star differeth," says the Bible, "from another star in glory." Our own sun is probably one of the smaller ones. Betelgeuse (bĕt'ĕl-gûz'), a giant who decorates a shoulder in the group of stars we know as Orion, is one of the largest; he is some 250,000,000 miles across—or three hundred times thicker through than our sun. If the sun were placed at this great fellow's center, the whole orbit of our earth would fall inside his outer edge, and even Mars would be only a little way outside his surface. His total bulk must be about 25,000,000 times greater than the sun's; and he gives 1200 times more light, although he is so far away that to us our own good sun seems to outshine the great monarch sixty thousand million times. But if we should wake some morning to find that a mischievous sprite had exchanged him for our sun, we should be dismayed to see him filling nearly all the sky.



These are the famous creatures who, as the ancients believed, were strung along the sun's annual path through the heavens. Now we know that it is not the sun which travels. What really happens is that, as we on earth swing round him once a year, we see him against a different group of stars in each successive month. The diagram above will make this clear. It shows the sun in the center, with the earth's orbit faintly outlined around him. You will notice that anyone standing on the earth on March 1st and looking toward the sun, would see him against the constellation known as Aquarius, or the Water Carrier. A month later the earth would have moved forward in its path, and the sun would then be seen against the constellation known as Pisces, or the Fishes. And so it would continue, throughout the circle of the year. If you will memorize these few lines, you will never have any trouble in recalling the order of these famous constellations that were once supposed to have such a powerful influence in the affairs of men:

The Ram, the Bull, the Heavenly Twins,
And next the Crab the Lion shines,
The Virgin and the Scales;
The Scorpion, Archer, and the Goat,
The Man that holds the watering pot,
And Fish with glittering scales.

Stars are classified according to their brightness. Sirius (sĭr'ĭ-ŭs), a beautiful white star that is seen at his best in March and is known as the Dog Star, is the most brilliant in the sky; or as we say, he is a star "of the first magnitude" (măg'nĭ-tūd).

It was the Greeks who began the custom of classifying stars according to their brilliance. The brightest ones they ranked as being of the first magnitude, and those just to be seen by the naked eye as of the sixth magnitude. All the others were graded between the first and sixth. Of course the telescope has shown us stars a great deal dimmer, but we still classify them after the manner of the Greeks, down to the twenty-first magnitude the higher the magnitude the less bright the star.

A star of the first magnitude is exactly a hundred times brighter than one of the sixth magnitude. In the whole sky there are only twenty of the first magnitude. Some sixty stars are of the second magnitude or brighter. Five thousand stars are brighter than the sixth, and more than a million are brighter than the twelfth magnitude. The great telescope on Mount Wilson, California, shows probably not less than a thousand

million stars of the twenty-first magnitude or brighter.

How Many Stars Are There?

No one has ever been able to count the stars - which scarcely seems strange when one realizes that through a large telescope hundreds of millions are to be seen. It probably is no exaggeration to say that they are countless, for stars that are a million times too faint to be seen with the eye will still show on a photographic plate. Who knows what larger and more powerful telescopes may yet reveal!

Of the hundreds of millions of stars in the sky, only some six thousand are visible to the unaided eye - and even these are hard to count. Since we can see only one-half of the heavens on any given night, only about three thousand stars can be counted without a telescope. But even this number varies as the earth turns on its axis, for the stars are scattered unevenly through the sky. Moreover, the atmosphere is not always equally dense, and so the number varies with the state of the air.

Some stars are dashing through the universe at a tremendous rate of speed. Here is one, for instance, that could encircle the earth twice while an express traveled only one mile on the earth's surface.

And yet all the millions of stars give us less than one per cent of the light that is shed by the full moon - such is their tremendous distance away from the earth.

It is only since 1823 that astronomers have been able to find out what the stars are made of, for it was then that a German scientist named von Fraunhofer (fŏn froun′-hō-fẽr) discovered that different kinds of light, when split into their different rays - as by a prism or a rainbow - showed differing arrangements of very fine lines. This first hint enabled students to classify the stars into three groups. But there the matter was dropped for almost forty years. Then in 1860 another German scientist, Kirchhoff (kĭrK′hôf), gave a fuller explanation of the meaning of the lines. The work was carried on by an Italian priest, Father Secchi (sĕk′kē), and an Englishman, Sir William Huggins, both well-known scientists. Finally a great catalogue showing the composition of more than two hundred thousand stars was begun by Professor Pickering (1846-1919) at the Harvard Observatory.

We know now that the universe is all made of the same stuff. Red stars show iron, sodium, calcium, and carbon, common substances on our earth. Sodium, for instance, enters largely into common salt. White stars show large quantities of two gases known as hydrogen and helium in their outer envelopes.

We speak of stars as "fixed" because no one of them ever seems to move from his age-long abiding place in the heavens. But like so many things that "seem," this too is a mistake. No stars are really fixed; they are all moving, and most of the bright ones march in two great processions that go in opposite directions through the heavens—each one held to a fixed course by laws that cannot change. This march is the "star drift." But they have not all the same rate of speed. Some race so fast that scientists may easily track their courses among the slower stars, and others go so slowly that they must be watched for many years before they can be seen to have moved a

All thi as been discovered through the telescope. To anyone looking through its great eyestalk, a given star will soon seem to pass completely out of sight. But this is only an apparent movement, caused by the fact that our own earth is spinning rapidly - it is we who move and not the star. The actual movement of a star among the other stars seems very small indeed, even when the star is fairly near us. Alpha Centauri (ăl′fȧ sĕn-tô′rī)—which simply means that the star in question is the brightest in the group of stars we call the "Centaur"—is nearer to our earth than any other star, and goes speeding through the heavens at the rate of fourteen miles a

second; yet in a single day it seems to move less than a fifty millionth of the distance across the sky.

The sun rushes through space at the rate of twelve miles a second, but he is slower than the average star. A few stars travel forty miles a second, and one has worked up the terrific speed of seven hundred miles a second.

"But what about collisions?" you may ask.

They may, perhaps, occur; we do not know. But so ample is the space the universe affords that certainly they do not happen often. One learned man has said: "The chances of an encounter in the boundless deserts of space are no greater than the chance of two tennis balls meeting out of twenty that might be adrift in a hollow space as large as our earth."

We say the universe is spacious. Alpha Centauri, the nearest star, is a mere 25,000,000,000,000 miles away--275,000 times farther than the sun; but other stars are unbelievably more distant. No human being can imagine distances so vast. A ray of light, which travels at the startling speed of 186,300 miles a second—or eleven million miles a minute—takes over four years to reach us from the nearest star. Or, as astronomers phrase it, the star is four "light years" away --a "light year" being the distance a ray of light will travel in a year, or about six trillion miles. Some of the stars are so far off that their light has taken many thousands of years to come to us. Such stars would seem to us to be still shining though they had been blotted out thousands of years ago. Some of the light that you will see when you look up at the stars to-night started on its voyage to you long before the time of Christ.

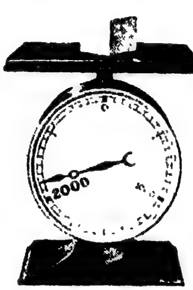
If it seems strange to you that we can measure the distance to a star when we can never leave the earth we stand on, just examine this diagram. At the right you will see the sun, with the earth's orbit faintly outlined around it and the earth shown at the points it would have reached on June 21st and December 21st. Those two points are 186,000,000 miles apart, for they are situated on opposite sides of the orbit at its widest part. Now turn to the smaller diagram at the left. You will see at the bottom of the picture a small representation of the large diagram that we have just been explaining, but at the top of the drawing is a star. All the astronomer needs to do is to sight to the star on June 21st and measure the angle that a line connecting the earth and the star would make with a line drawn straight across the earth's orbit to the point on the opposite side. Then he waits till the earth has swung around on its orbit to the position it occupies on December 21st. At that point he sights to his star again, and again he measures the angle that the long line to the star makes with the line across the earth's orbit. A comparison of those two angles measured at different seasons of the year, and a little figuring, will now give him the distance to the star. All he has to know is the distance across the earth's orbit and the size of those two angles.

But how on earth can we ever find how far away a star is? How can we find out how far away anything is if we cannot go to it? Well, any Boy Scout who has finished his training can answer that question. If he wants to know how wide a river is without rowing across it, he begins by drawing a line between two points A and B on his own side of the river. He measures the length of that line. Then from A he sights at a point X on the other side of the river and finds out the size of the angle made by his line from A to B and a line from A to X. Similarly, he sights from B to X and measures the angle. When he knows the size of these two angles, he does a little sum in geometry, and presto! the answer is the distance across the river.

Now the same principle applies in finding out the distance to a star. But at first there was a difficulty which seemed impossible to overcome. Any line that we could get along the earth was so short in comparison with the distance to the star that when we sighted from the two ends of the line, the difference in the angles was too small to show; so there was no way to find out the distance to the star. The longest line from which we can sight on the earth is 8,000 miles--the length of the earth's diameter. But sighting at a star from two points only 8,000 miles apart, was just like sighting twice from the same point.

Then a German astronomer named Bessel (1784–1846) had a brilliant idea. On the twenty-first of June the earth is very far from where it was on the twenty-first of December. It has swung half way around the sun in the meantime; and it is 186,000,000 miles away from where it was, for that is the distance across the earth's orbit. Bessel sighted his star in June and again in December and found that the problem was solved. His angles were still very small, and his calculations very hard to make. It was just about as if he had been measuring a baseball twenty-five miles away. Yet the distance to the star was found with a fair degree of accuracy. This is what we call "determining the parallax" (păr'ă-lăks) of a star. Bessel's discovery as to how it might be done is regarded as one of the great achievements of science.

The lights that you will see tonight if you look up at the sky were shining when the first man appeared on earth and very long before that. For ages men have looked up at the same star patterns that you and I see now. It is hard to think of anything more unchanging.



On these scales you see a cubic inch of a small star that is a companion to the bright star Sirius. It will probably be hard for you to believe that the figures on the dial represent its weight in pounds, but that is nevertheless the case. For a single cubic inch of this amazingly solid little weighs over a ton.

And yet even these lights do sometimes go out. There are said to be as many dead suns in the sky as living ones. Every star's career must some day come to an end. Then, like a cold ghost, it wanders through space for endless ages, but as a shining sun its glory has departed.

Do Stars Ever Go Out?

Stars never can burn up and turn to smoke and ashes. They can only cool off, and grow dark and solid; for when their surface cools and hardens it can give out light no longer, and we can see them no more. So their history is the same as that of our own planet, though vast ages may be needed to complete it. Our own sun, which is by no means dying, is surely several trillion years old.

As a star grows old its body shrinks and shrinks, by reason of its own gravity. Its sphere of glowing gas may vary in size from a globe no larger than our earth to one so big that it could contain almost the entire orbit of Jupiter. Such a mass may be ten thousand times thinner than our atmosphere or a good many thousands of times denser than water. In this respect a little companion star to Sirius is one of the most remarkable in the sky. It is about the size of the planet Uranus, but it is much hotter than our sun, and in spite of the great difference in their size, their weights are almost equal. This solid little fellow is so heavy that one cubic inch of him weighs a ton; he is more than two thousand times heavier than if he were made of gold. Stars of this dense, glowing type are known as "white dwarfs."

But even though stars must go out some day, modern discoveries as to the nature of matter and the source of the sun's heat make it hard to see why a star should not keep on shining for unimaginable ages.

When a star is first born it is not necessarily very hot. Its color is then a dull red– about the color of iron which is beginning to grow hot. But it soon begins to shrink, and as it shrinks it grows hotter and hotter, taking on a yellowish tinge, just as the iron does as its temperature rises. When the star reaches it period of greatest heat it turns to a gleaming white. Iron behaves in the same manner when raised to a very high temperature. And like metal, when a star begins to cool it turns first yellow and then red and gradually ceases to glow at all. Its light has then gone out forever.

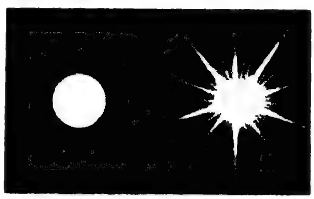
How We Guess the Age of a Star

In this way the age of a star can be determined by its color. The large, dull red stars that are gradually turning yellow are the young ones. Such is Betelgeuse. The white stars are middle-aged, and the yellow stars that are gradually turning red are getting old. Eventually they will all go out and turn cold and solid like the earth. But meanwhile others will be born.

There are certain stars that vary from time to time in brilliance; we call them "variables." Now they are very bright, and now quite faint—possibly even a thousand times brighter at one period than at another. The change is usually quite regular, though in some cases it takes only a few hours and in others hundreds of days. The exact cause is not certainly known, but it is thought that the stars are pulsating—that is, growing first larger and then smaller—and that their brightening and dimming result from the motion.

But other stars vary for quite a different reason. These are "twin stars"—stars that are double or even made up of several bodies, often so close together that they look like a single point of light, just as the two headlights of a motor car will look like one when they are far away. There are some twenty thousand of these double—or "binary" (bī'nȧ-rĭ)—stars. Indeed, it has been suggested that single stars such as our sun may be more rare than double stars.

Binary stars circle around each other, sometimes so close together that they scrape but sometimes so far apart that it takes many years for them to make the trip. If one is dimmer than the other and is so placed that it comes at times between us and its brighter mate, they will look to us like a single variable star—dim when the dimmer member of the pair is next us and bright when it has moved out of the way.



At the left is a planet, a clear round steady light that does not twinkle. At the right is a star. It always twinkles, for its rays come so far that no matter how big the star may be, it looks like the merest speck of light, and its rays are easily swerved from side to side as they travel through our atmosphere. That wavering is what makes the star twinkle.

Algol, the Demon Star

Such is Algol—a word meaning "demon" in the Arabic—which is a bright star of the second magnitude except for a few hours every day and a half, when its light is dimmed to a quarter of its ordinary brilliance. This star, and the others like it, are called "eclipsing binaries"; and binary stars that are so far apart as to be seen through the telescope as two stars are called "visual doubles"—that is, "stars that are seen to be double."

Occasionally two stars that are not really a pair and have no relation to each other are so placed—one behind the other—that they look like a single star, even though they may be millions of miles apart. Such stars are called "optical doubles"—that is, "stars that look double to the eye."

Strange Visitors of Star Land

In 1885 a brand-new star blazed forth, estimated to have been a hundred times as brilliant as the sun. For a few days it reigned supreme among its fellows, the brightest star that ever had been seen. But its flaming career was short. In a few days it disappeared and never has been seen again.

Another famous infant prodigy was seen by Tycho Brahe (tē'kō brä'ē), a great Danish astronomer of the sixteenth century. On his way home one night from his observatory, he saw a bright star overhead which he had never seen before. He knew the heavens all by heart and could be in no doubt that this was a stranger; and yet it seemed ridiculous to think a new star had been born. So he called some of his servants to assure him that the star was really there. Then he went to his observatory and recorded the newcomer's exact position, meaning to watch it and discover whether it was a planet or a so-called "fixed star." He was a good deal twitted by his friends as to his latest find, though he was always able to reply by pointing it out to them. But after three weeks, the splendid visitor began to fade. It managed to last a little longer than a year and then its light went out.

When a Star Explodes

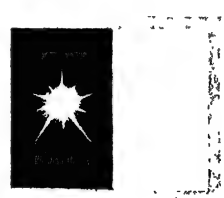
We believe a marvel of this kind is caused by some tremendous explosion of gases within a star, or by friction that heats up a star for a while as it is passing through some ocean of heavenly vapor. But we are none too sure about all this. We call these stars "novae" (nō'vē), from the Latin word

for "new." They flare up rapidly, but gradually fade away, and usually disappear entirely.

The stars are always shining. When the sun comes up they disappear because he is too bright for them. We can see a white mark on a dark object, just as we see the stars in a dark sky; but we could not see the mark if the object were all as white as the mark is, and we cannot see the stars when the sun has made the whole sky as bright as they are. Yet we can often see the moon, and even the planet Venus, in broad daylight, and through a telescope a score of stars are visible. It is often said that from the bottom of a well the stars can be seen at any time of day, but this is a mistake. No one has ever been found who saw them there.

On a planet without atmosphere the stars would never be put out by the sun, for the background of the sky would always be black. It is the reflection of the light by every tiny particle of our air that makes the bright blue sky. In vacant space all is as black as night except when one is squarely in a ray of light.

In most places the easy way to tell a star from a planet is to see whether it twinkles. For stars twinkle and planets do not. A star is so far away that it is like a mere point of light. So, when its tiny ray meets irregularities in the different layers of our air, it cannot travel through them quite smoothly. It will quiver and waver, or, as we say, it will twinkle.



This will show you why we cannot see the stars in the daytime. At the left you see a star shining clear against the dark night sky. Now though you may not believe it, the stars are shining as brightly at noon as at midnight, but because the sky is as bright as they, you can no more see them than you could see the star shown here if it were placed on the white patch at the right. Remove its black background and instantly it sinks out of sight.

How to Find the Planets

But the ray from a planet comes from a body so near us as to seem considerably larger; and so, instead of issuing from a mere gleaming point, it is shed from something a little more like a round disk. It is much harder for so large a ray to be displaced. Consequently, planets do not wink. They shed a steady light, as do the sun and moon. Yet in this matter the little planet Mercury is a law unto himself; he always twinkles more violently than any neighboring star. In fact, his winking is the surest sign by which to recognize him. The Greeks were conscious of his habit and dubbed him "the twinkler." It is a puzzling trait; astronomers are at a loss to explain it.

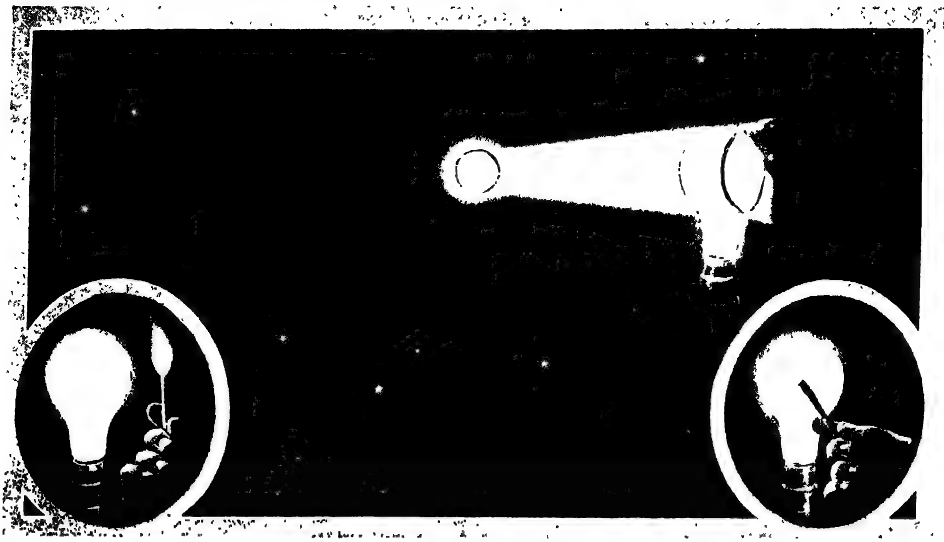
What Makes the Stars Twinkle?

The nearer a star is to the horizon the more violently it winks, because its rays then have to travel through a greater thickness of quivering atmosphere than when it is overhead. The red stars twinkle least, while yellow ones twinkle more vigorously and white or bluish ones the most of all.

Look out some night through a window placed over a steam radiator at a street light a little way off. The waves in the air caused by the rising heat will make the light appear to wink and twinkle just as a star does and for the same reason. Or when you are motoring over an asphalt road on a hot day in summer, notice, as you near the top of a hill, the action of the rising waves of heat—how they seem to distort the surface of the road. In exactly the same way a ray of light gets out of shape in traveling to us through our atmosphere.

Stretching in a silvery band from north to south across the sky is the great belt of misty light we call the Milky Way or the Galaxy (găl'ăk-sĭ). This bright belt forms a full circle all the way around the heavens and is made out of millions of very faint stars clustered together, with many brilliant stars ranged near it on either side. On a clear, moonless night it is the most striking feature in the sky; for the stars in it are so thick that it looks like a great cloud made out of star dust. If we think of the Milky Way as the metropolitan center of the heavens, the sun and all his family of planets may be compared to a little farm group in a thinly populated country district.

Under a telescope this gleaming haze jumps into a multitude of faint stars making a vast, powdery circle through the universe.



If it were not for the earth's atmosphere we could see the stars as clearly in the daytime as at night, for the sky would always be black. But the air spreads the sun's rays so that the sky is bright whenever the sun is up. Against this bright background the stars are invisible. In other words, it is as if you held a flaming match against a lighted incandescent bulb. In the oval at the left the flame has a dark background and you see it quite clearly, but in the right-hand oval the flame is being held against the lighted bulb and does not show at all. The sun's rays penetrating our atmosphere blot out the stars just as the light from the bulb acts to blot out the flame of the match. They cannot show against their background.

It is estimated that a single photograph of the densest region, if taken through the powerful telescope on Mount Wilson, will show two or three billion faintly glowing suns. They are massed together in groups that are from five thousand to forty or fifty thousand light years across. Our own sun and all the brightest stars belong to one of these groups.

What Is Our Universe?

The universe that owns this starry girdle is spread out through space in the form of an enormous flattened sphere—shaped, we may say, very much like a watch—and so vast is it that a ray of light needs about 250,000 years to travel across it. As we have said before, the stars are always pacing through these great heavenly spaces, each in its accustomed path. Some move so fast, however, that they some day may leave our universe entirely—perhaps to journey to another which we know nothing of. For the boundary of our starry universe is reached when there is no longer a body still beyond which is attracted mainly by a body within the universe.

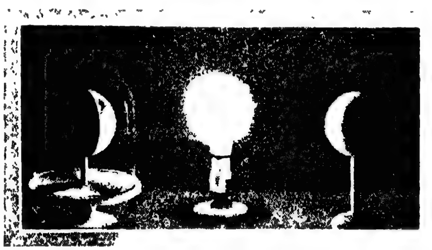
Our own universe is large enough to be beyond the wildest dreams of the imagination. So when you gaze up at the Milky Way, you must try, if you can, to realize that you are looking at billions of glowing suns, many of which may be warming worlds like our own. You happen to be placed about midway in the watch between the face and back, but a good deal to one side of the center of the circle. Now if you look toward the face or back, so to speak, the stars will not appear so thick because they are not spread out so far in those directions; but if you turn toward the round rim of the watch, they will look thick enough to form the Milky Way, because they run so far in that direction. In a word, when we look up at the Milky Way we are simply looking through the universe where it is longest, and of course we see more stars. Such a glimpse at the billions of suns in a single universe will make us realize, as perhaps nothing else can, that neither you nor I can be the center of it.

The men of old knew well enough that it is hard to find a given star on a clear, moonless night, when all the sky is glowing

with its thousands of lights. So they divided the more brilliant stars into familiar groups, which even modern men are glad to use as guideposts. The groups are known as "constellations" (kŏn'stĕ-lā'shŭn). None of them are hard to make out, and once we know their faces, they greet us like old friends--the faithful Bear, the lovely Pleiades (plē'yȧ-dēz), Orion (ō-rī'ŏn) the great huntsman, and the Swan.

Each star has, so to speak, a given name and a surname. The given name is a letter of the Greek alphabet, while the surname is that of the constellation. The brightest star in the constellation will be Alpha, the Greek A, the next brightest will be Beta, the Greek B, and so on down through the alphabet. Thus "Alpha Canis Majoris" means the brightest star in the constellation whose name, translated into English, means the "Larger Dog." This is the star we also know as Sirius, for very brilliant stars have names of their own, aside from those they take as members of a constellation.

At first it is a little disappointing to learn that an entirely formless set of stars is the famous Ram or the Dragon or the hero Perseus. For the imagination of the early Chaldeans and of the Greeks carried them a long way, we must admit, in tracing likenesses. But without their poetic fancies it would be much more difficult to memorize the starry patterns. Their crude maps of the heavens have entirely disappeared, lost in the long ago, but they served their purpose. An early one was made by an ancient Greek astronomer named Hipparchus (hĭ-pär'kŭs), who died about 130 B.C.; but the earliest list that has come down to us is in the Almagest (ăl'mȧ-jĕst), an astronomical work by the famous Ptolemy (tŏl'ĕ-mĭ), an astronomer who lived in Egypt



Above you may see the effect of air in spreading rays of light. All the air has been withdrawn from under the glass dome at the left; in other words, what we call a vacuum, or perfectly empty space, has been created inside the glass. As a result, the globe inside the vacuum, although it is exactly like the globe you see at the right, shows only where the lamp's rays are shining directly upon it. The rest of the globe is in a shadow so black that nothing shows at all. But the globe at the right, which stands out in the air, can be clearly seen even on the side that is in shadow, for the air spreads the rays of light so that they illuminate even those areas where direct rays do not strike. This is what makes the whole sky bright even in those patches where there are no sun or stars. If it were not for the air, the sky would always be blacker than at midnight.

in the second century after Christ. It contained 1080 stars.

As the obedient earth pursues her year-long path around the sun, she sooner or later sees her glowing lord from every point in the circle. We now know that it is ourselves who travel; but to the ancients, who felt they were the unchanging center of the universe, it was the sun that seemed to make an annual trip round the whole circle of the heavens. Measured by the constellations, he seemed to move through a great path from month to month, along which were strung a dozen groups of stars that never changed position. These stars were given names of animals and gods that had interesting connections with the various months--stories that would take too long to tell here.

What really happened was that, sighting from the earth, men would see the sun, in each succeeding month, against the background of a different group of stars. These star groups, then, would make a belt entirely round the heavens; and along the center of this belt or road would run the sun's annual path, which we commonly refer to as the "ecliptic" (ĕ-klĭp'tĭk.).

Now almost all the constellations which stood along this apparent course were named for animals; so the great road was called the "zodiac" (zō'dĭ-ăk), from a Greek word meaning "a circle of animals." Part of the word we see in other forms which use the Greek for "animal"; "zoo" and "zoölogy" are both made up in part from the Greek "zoon," meaning "animal."

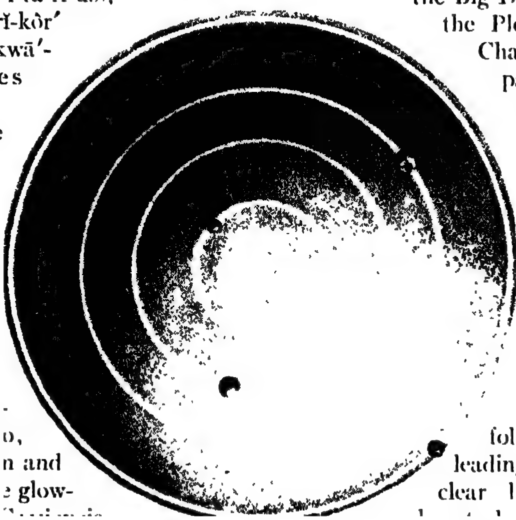
What Are the Signs of the Zodiac?

Beginning with the opening of spring, the sun was seen against—or was said to "enter" —the following constellations, one for each month until the next spring: the Ram, the

Bull, the Twins, the Crab, the Lion, the Virgin, the Scales or Balances, the Scorpion, the Archer, the Goat, the Water Bearer, and the Fishes. These are the creatures that form the "signs" of the zodiac; you see them in every almanac and they are often used for decoration elsewhere. They are commonly referred to by their Latin names, which we will give in order, as above: Aries (ā′rĭ-ēz), Taurus (tô′rŭs), Gemini (jĕm′ĭ-nī), Cancer (kăn′sẽr), Leo (lē′ō), Virgo (vûr′gō), Libra (lī′brȧ), Scorpio (skôr′-pĭ-ō), Sagittarius (săj′ĭ-tā′rĭ-ŭs), Capricornus (kăp′rĭ-kôr′nŭs), Aquarius (ȧ-kwā′-rĭ-ŭs), and Pisces (pĭs′ēz).

But there are many other constellations besides these twelve. The Greek sky was alive with heroes who had been enthroned there, constantly reminding men of their brave deeds. Nor is there any reason why we, too, should not know them and delight in them. The glowing form of Hercules, [illegible] (kăs′ĭ-ō-pē′yȧ) in her glittering Chair, the giant square that marks the winged horse Pegasus (pĕg′-ȧ-sŭs), the diamond-studded Crown, and gleaming Cup, all have their pretty tales that make the sky a vast picture book.

Our maps will help you make these glowing personages your lifelong friends. Of course, anyone living south of the Equator will see a different set of constellations, unknown to the Greeks and therefore unpeopled by heroes of mythology. Of these the Southern Cross is probably the most famous.



Some of the stars that send us such a tiny ray are really suns so vast that their size staggers the imagination. Here, for instance, is Betelgeuse, a reddish star that we see in the constellation of Orion. If our sun and the solar system could be set down on top of it, the orbit of the planet Mars would fall only a little way outside the body of the star.

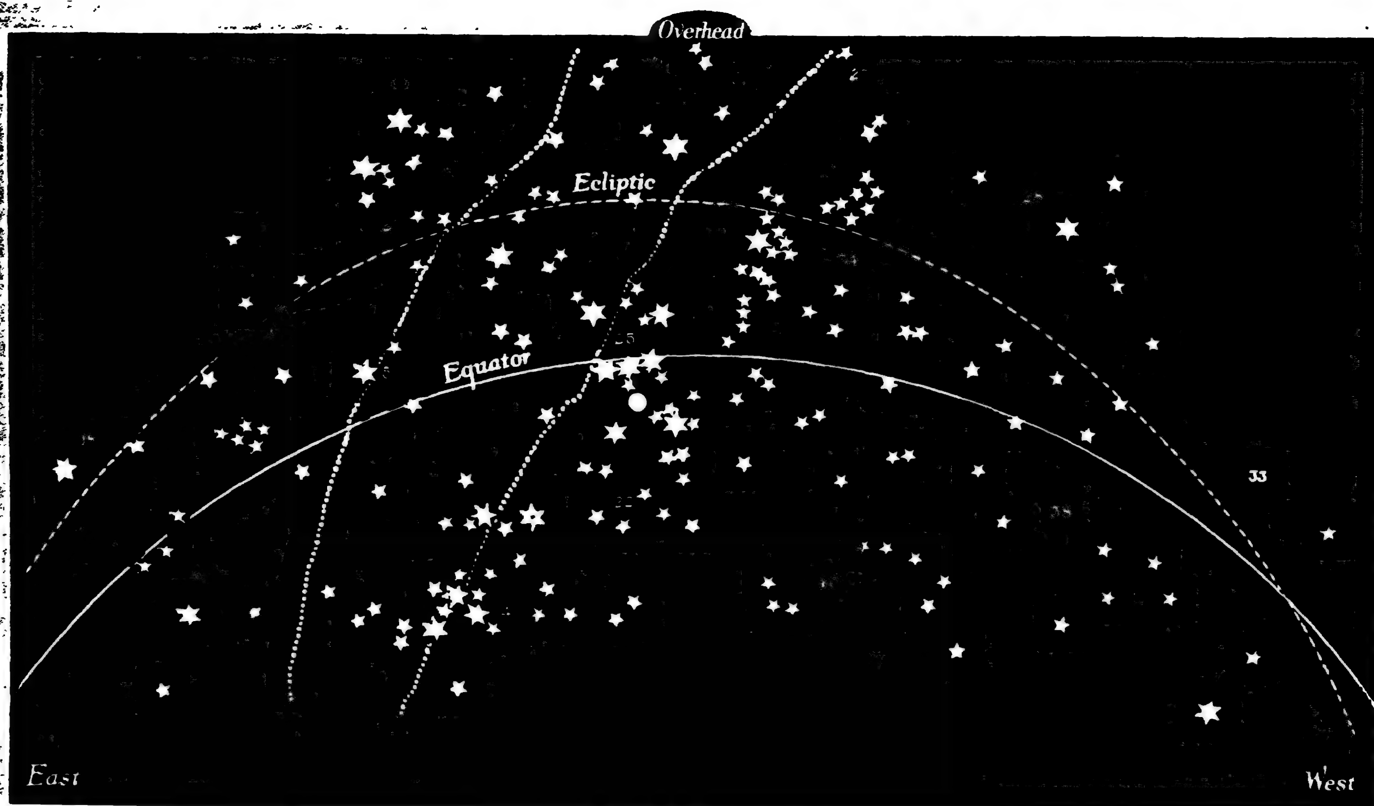
Why the Pole Star Never Moves

To anyone living north of the Equator, the "North Star"—the "Pole Star"—is the only one that never seems to move across the heavens; it always remains fixed high in the northern sky, for it is almost exactly over the North Pole. So even though the earth may spin around and always show us a changing "skyscape," this star can never rise or set, because the axis of the earth is always pointing toward it. It is almost as if the earth were hanging from it by a chain attached to the North Pole.

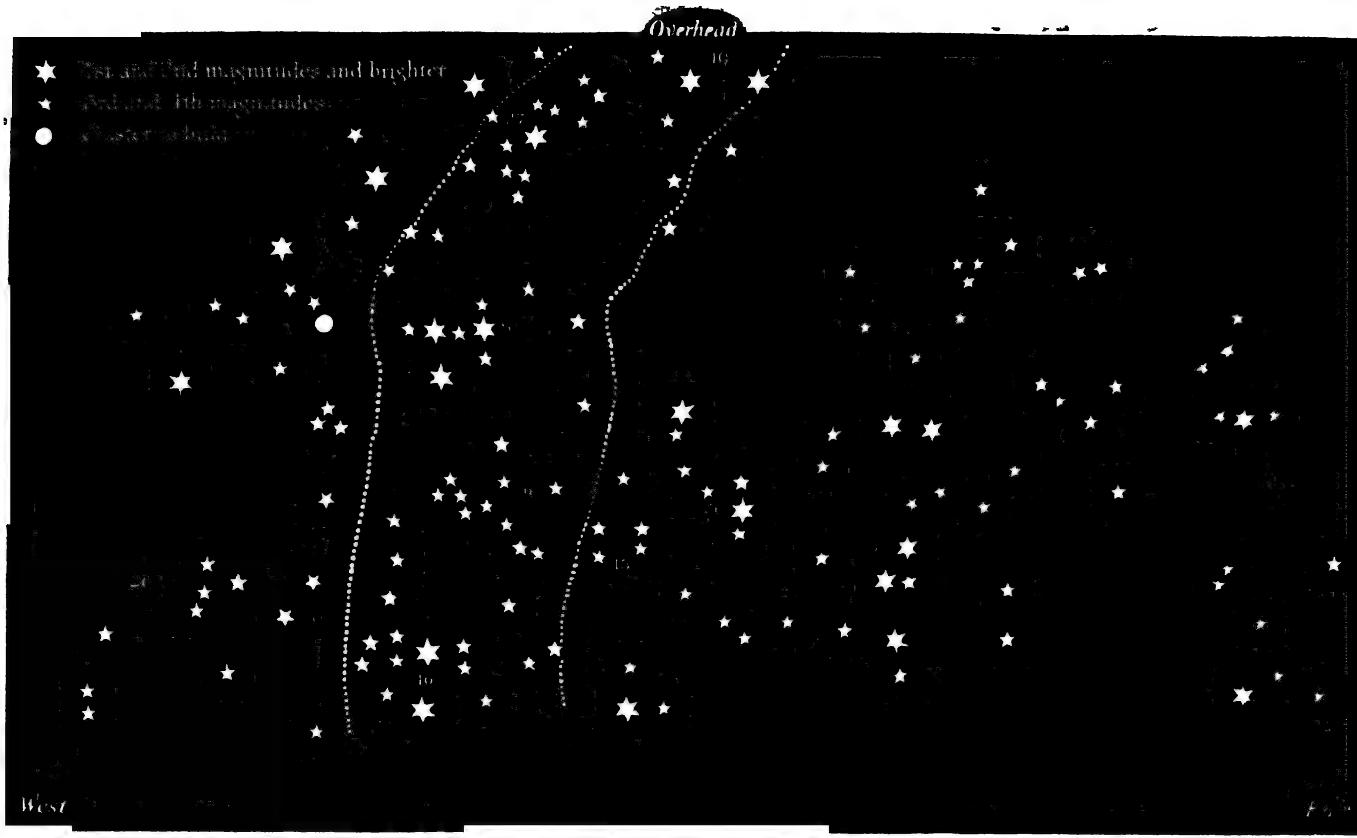
The Pole Star—or Polaris (pô-lā′rĭs) is not at all hard to find. Everyone knows the star group called in the United States the Big Dipper and in England the Plow, the Wagon, or Charles's Wain; it is part of the constellation known as the Great Bear—or Ursa Major (ûr′sȧ mā′jẽr). The two stars forming the side of the dipper that is farthest from the handle are called the Pointers, because they point toward the North Star. Let your eye follow a straight line leading along them up to a clear light star standing [illegible]e and you will have Polaris. It is really a triple star, fixed at the tip of the tail of the constellation called the Little Bear—Ursa Minor (ûr′sȧ mī′nẽr)—or the Little Dipper. Around it the Big and Little Bears and all the other constellations in the heavens seem to circle. Because they are so near the pole the two Bears never set, at least for dwellers in our northern latitudes.

Is the North Pole Changing?

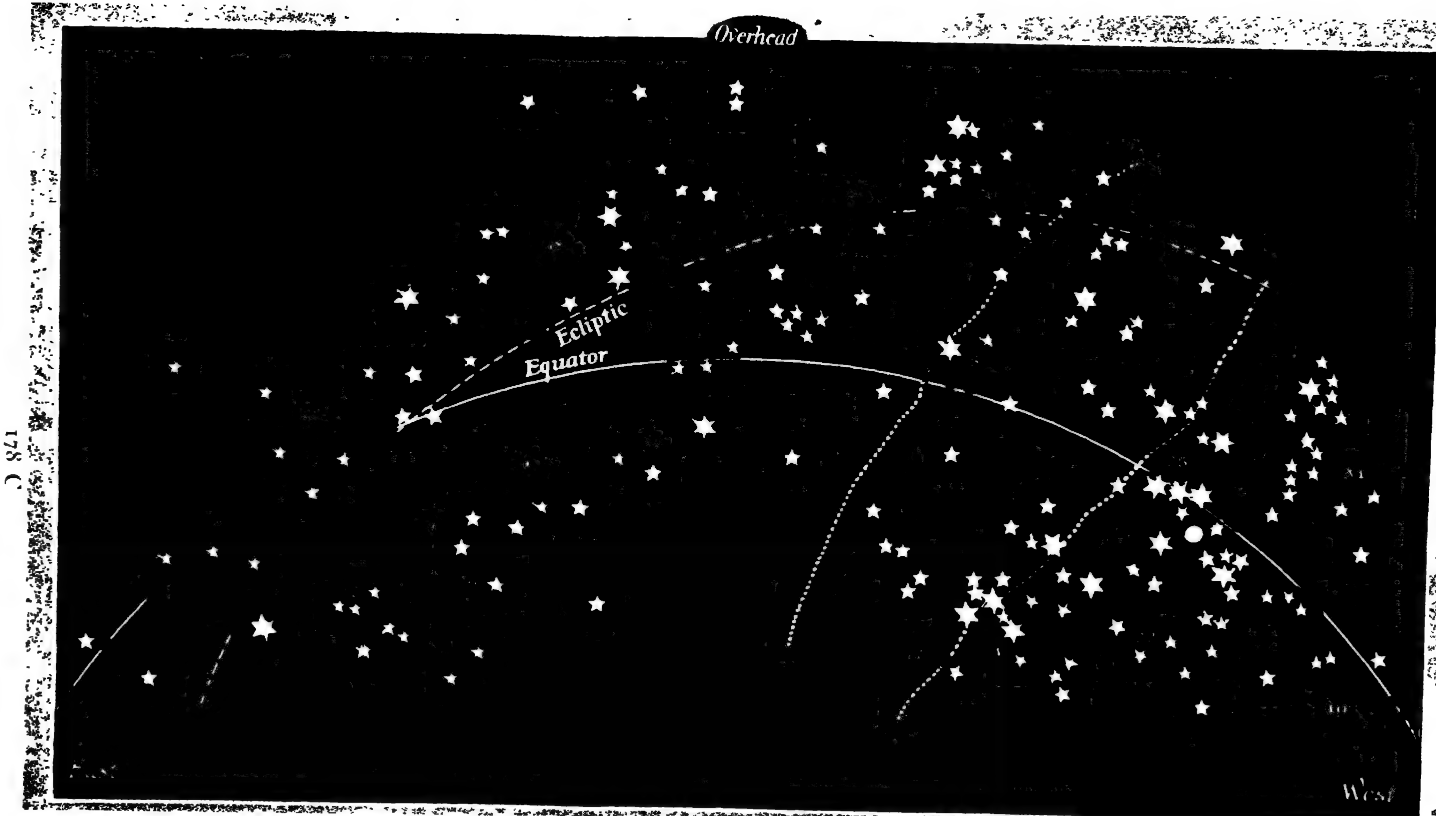
As a matter of fact, the Pole Star is not precisely over our North Pole; it is about two moon-breadths out of the way. For the position of the pole in the heavens is shifting ever so slowly. In about 12,000 years the bright star Vega (vē′gȧ), in the constellation of the Lyre, will have suc-



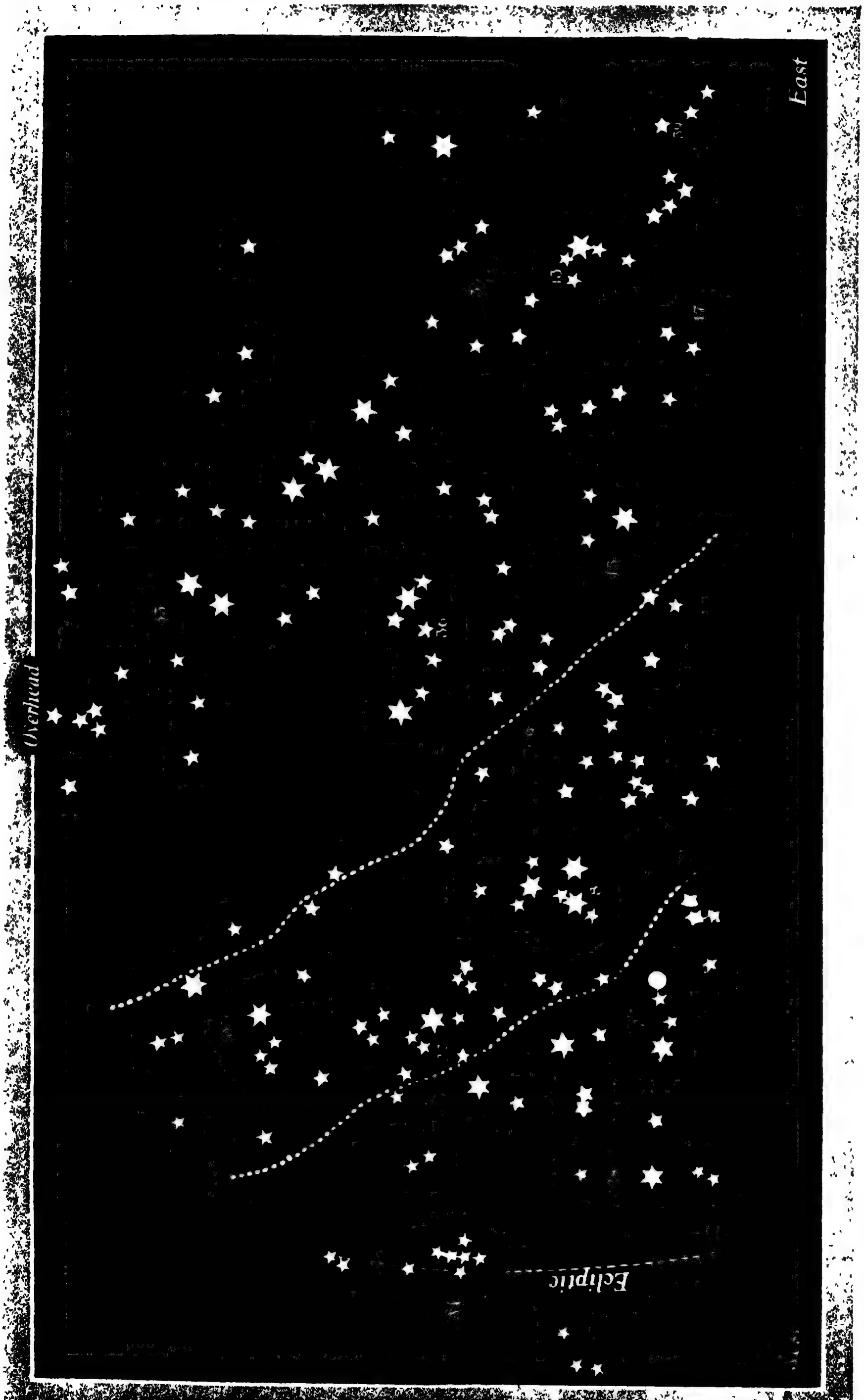
The constellations in the southern sky on an evening in January or February are: 4. The Big Dog, with Sirius, brightest star in the heavens. 5. The Little Dog; bright star, Procyon. 6. Cancer, or the Crab. 10. The Charioteer. 18. The Lion. 20. The Twins; bright star in head of twin at right, Castor; star in head of twin at left, Pollux. 22. The Hare. 25. Orion. 27. Perseus. 28. Aries, or the Ram. 33. Pisces, or the Fishes. 34. The Bull; bright star, Aldebaran; star group in head, the Hyades; star group in neck, the Pleiades. 38. The Whale. 39. The Snake; bright star, Alphard. 40. The River.



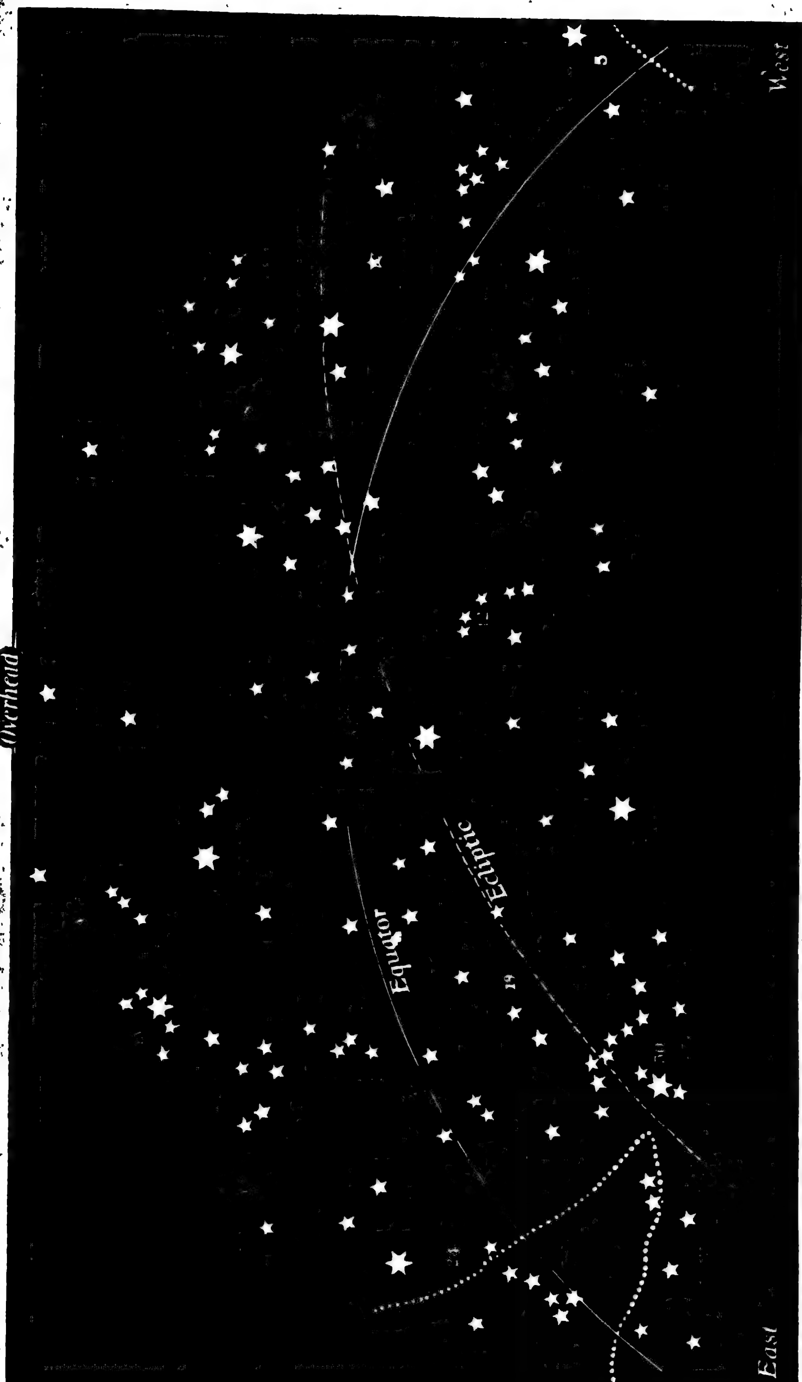
If you will look into the northern sky on an evening in January or February, you will see the constellations shown on this map They are as follows 2 Andromeda 3 Bootes 8 Cassiopeia 9 Cepheus 10 The Charioteer bright star Capella 15 The Dragon 16 The Eagle 18 Leo or the Lion 26 Pegasus 27 Perseus star at waist Algenib He carries the Medusa's Head, with its star Algol 35 The Great Bear or the Big Dipper, also called Charles's Wain 36 The Little Bear or the Little Dipper with the North Star, or Pole Star, at the tip of the tail The dotted lines outline the Milky Way



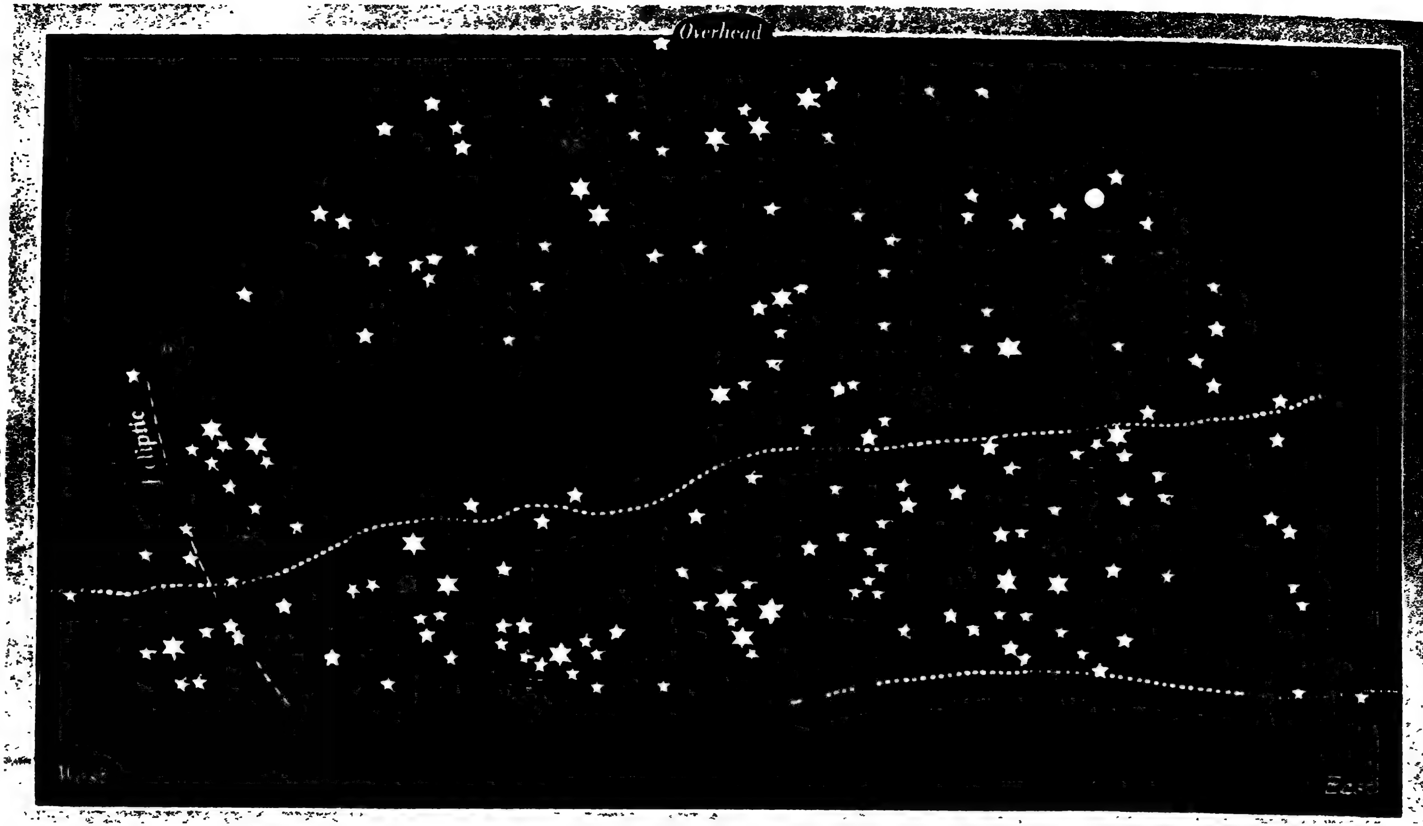
If you will look into the southern sky on an evening in March or April, you will see these constellations: 4. The Big Dog; bright star, Sirius. 5. The Little Dog; large star, Procyon. 6. The Crab. 12. The Crow. 18. The Lion, with Denebola on his tail and Regulus on his right leg. 20. The twins, with the bright star Castor at the right and Pollux at the left. 22. The Hare. 25. Orion; large star under raised arm, Betelguese; large star on raised foot, Rigel (rī'jĕl). 34. Taurus, the Bull, with the Hyades group in his head. 37. Virgo, or the Virgin; large star, Spica. 39. The Snake. 40. Eridanus (ē-rĭd'ā-nŭs), or the River.



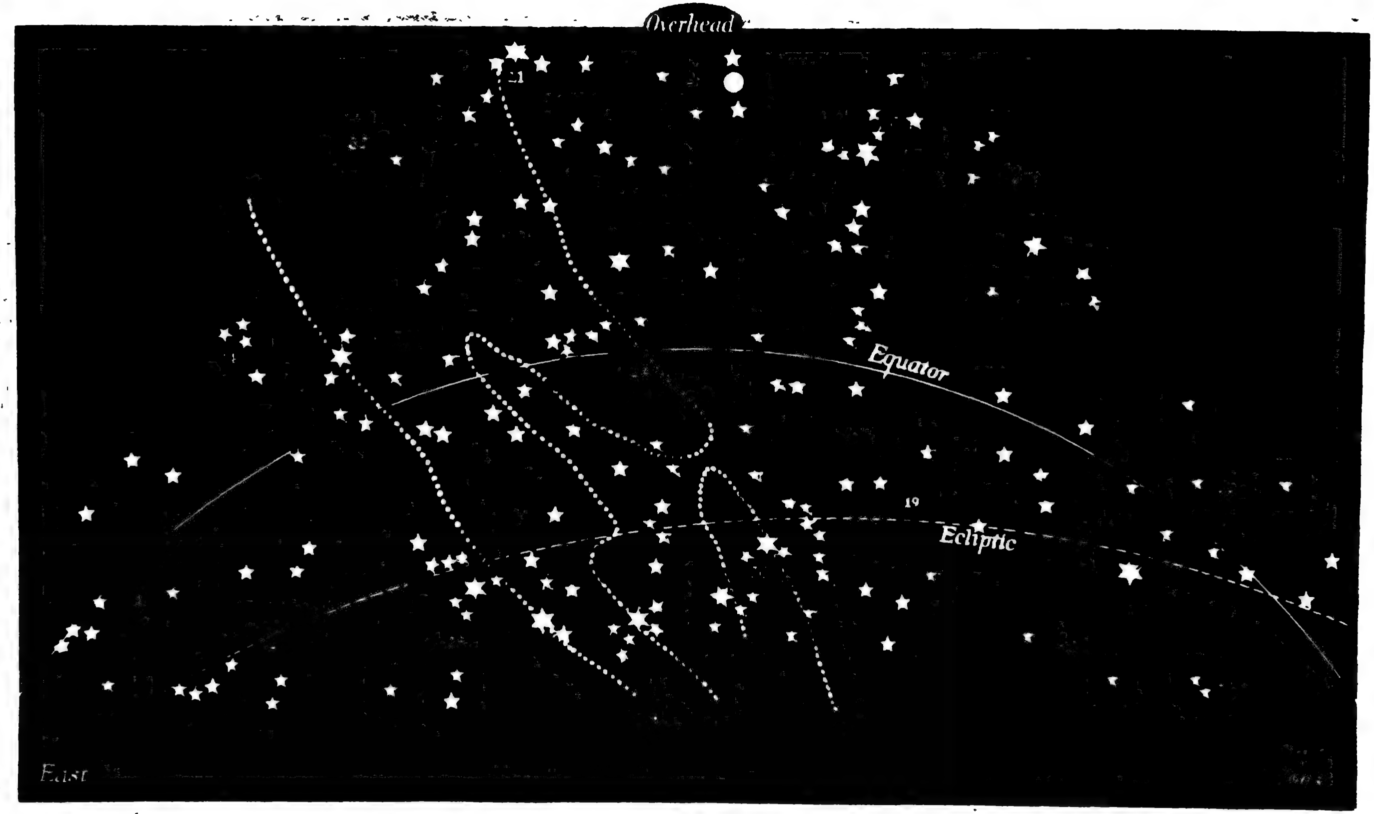
During March and April the northern sky at evening contains these constellations 2. Andromeda. 3. Boötes; bright star, Arcturus. 8. Cassiopeia. 9. Cepheus. 10. The Charioteer. 13. The Crown. 15. The Dragon. 17. Hercules. 27. Perseus, holding Medusa's Head, which contains the star Algol. 28. The Ram. 34. The Bull, with group known as the Pleiades. 35. The Great Bear, or the Big Dipper, Dubhe, the large star in the middle of the back, and Merak, the star just below it, are the "pointers," which always point toward the North Star. 36. The Little Bear, with North Star at tip of tail. 39. The Snake.



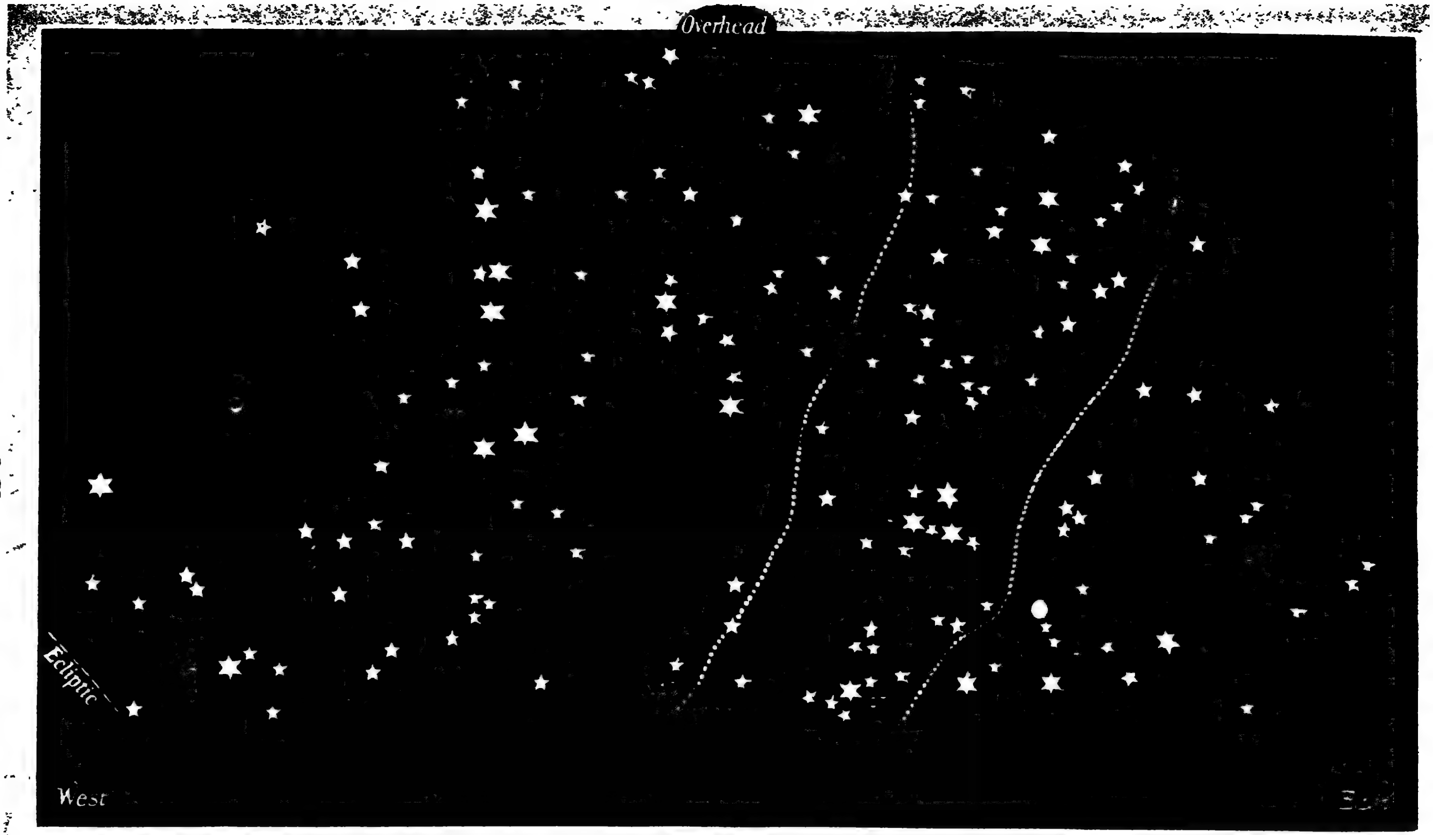
The southern sky on an evening in May or June contains these constellations: 3. Boötes (bō-ō'tēz), the Herdsman; bright star, Arcturus. 5. The Little Dog; bright star, Procyon. 6. Cancer, or the Crab. 12. The Crow. 13. The Crown. 17. Hercules. 18. The Lion; bright star on right leg, Regulus; on tip of tail, Denebola. 19. Libra, or the Scales. 24. The Man with the Serpent. 30. Scorpio, or the Scorpion; bright star, Antares (ăn-tā'rēz). 35. Ursa Major, the Great Bear, or the Big Dipper. 37. Virgo, or the Virgin; large star, Spica. 39. The Snake; bright star, Alphard.



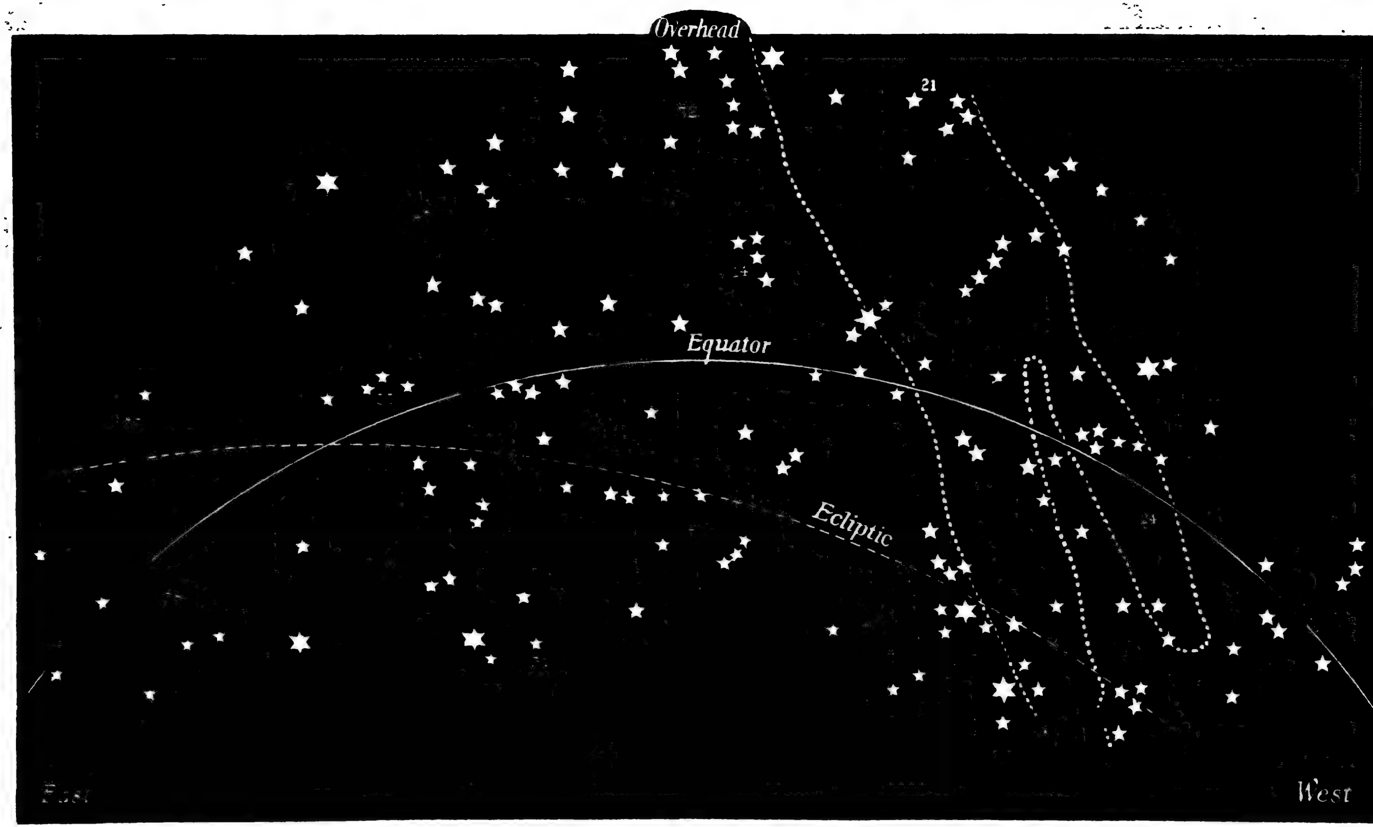
During May and June the northern sky at evening contains these constellations: 3. Boötes. 6. Cancer. 8. Cassiopeia. 9. Cepheus. 10. The Charioteer; bright star, Capella. 15. The Dragon. 16. The Eagle. 17. Hercules. 20. Gemini (jĕm′ĭ-nī), or the Twins, with Pollux at the left and Castor at the right. 21. Lyra, or the Lyre; big star, Vega. 27. Perseus; large star, Algenib. 32. The Swan; large star, Arided. 35. The Great Bear, or the Big Dipper, with the pointers Dubhe (dŏŏb′hē) and Merak, and Mizar as the middle star in the tail. 36. The Little Bear, or Little Dipper, with Pole Star at tip of tail.



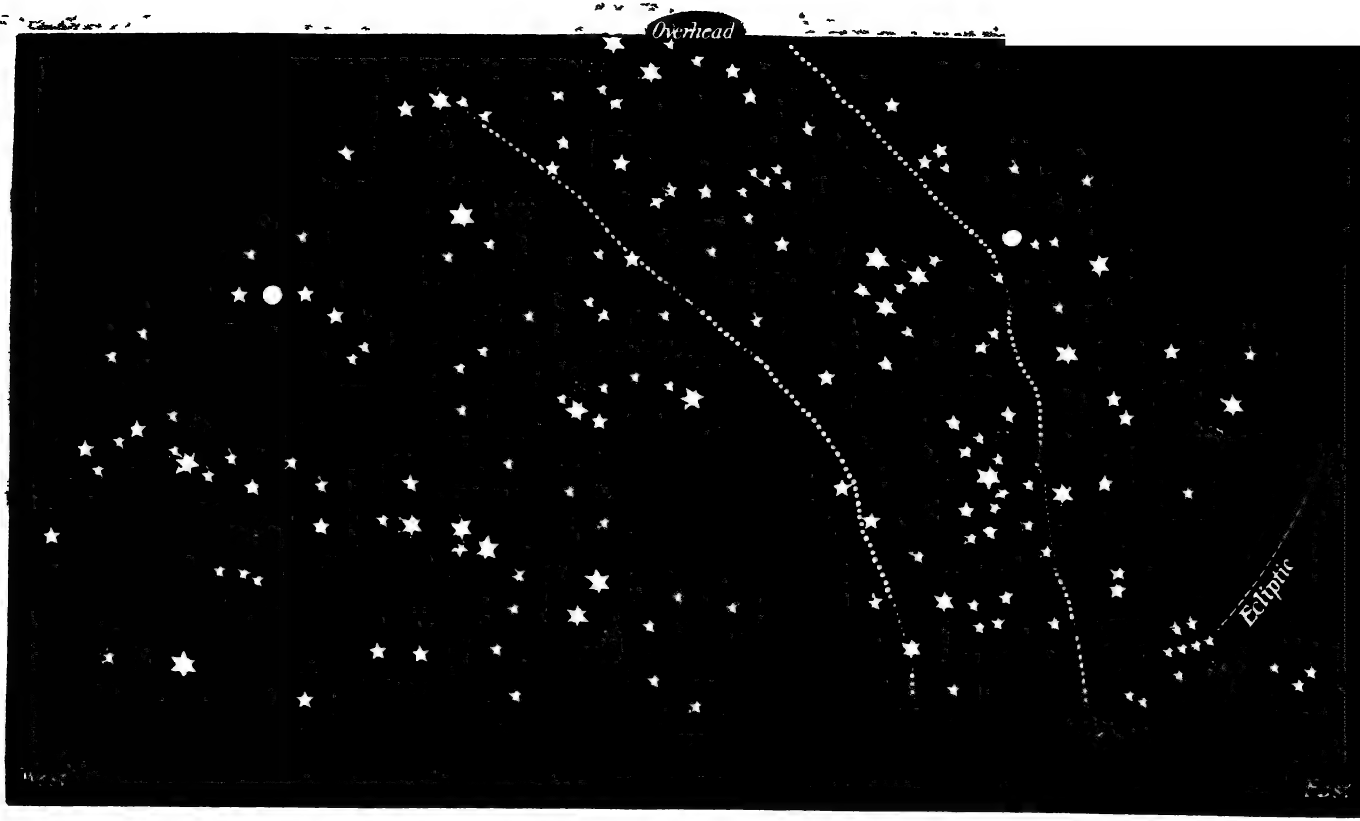
On an evening in July or August the southern sky contains these constellations: 1. Aquarius, or the Water Carrier. 3. Boötes. 7. Capricornus, or the Goat. 12. The Crow. 13. The Crown. 14. The Dolphin. 16. The Eagle, with the large star Altair. 17. Hercules. 21. The Lyre. 24. The Man with the Serpent. 29. Sagittarius (săj'ĭ-tā'rĭ-ŭs), or the Archer. 30. The Scorpion; big star, Antares. 32. The Swan. 37. The Virgin, with the large star Spica. 39. The Snake. The line marked "ecliptic" shows the seeming path of the sun; the one marked "equator" follows the plane of the earth's Equator.



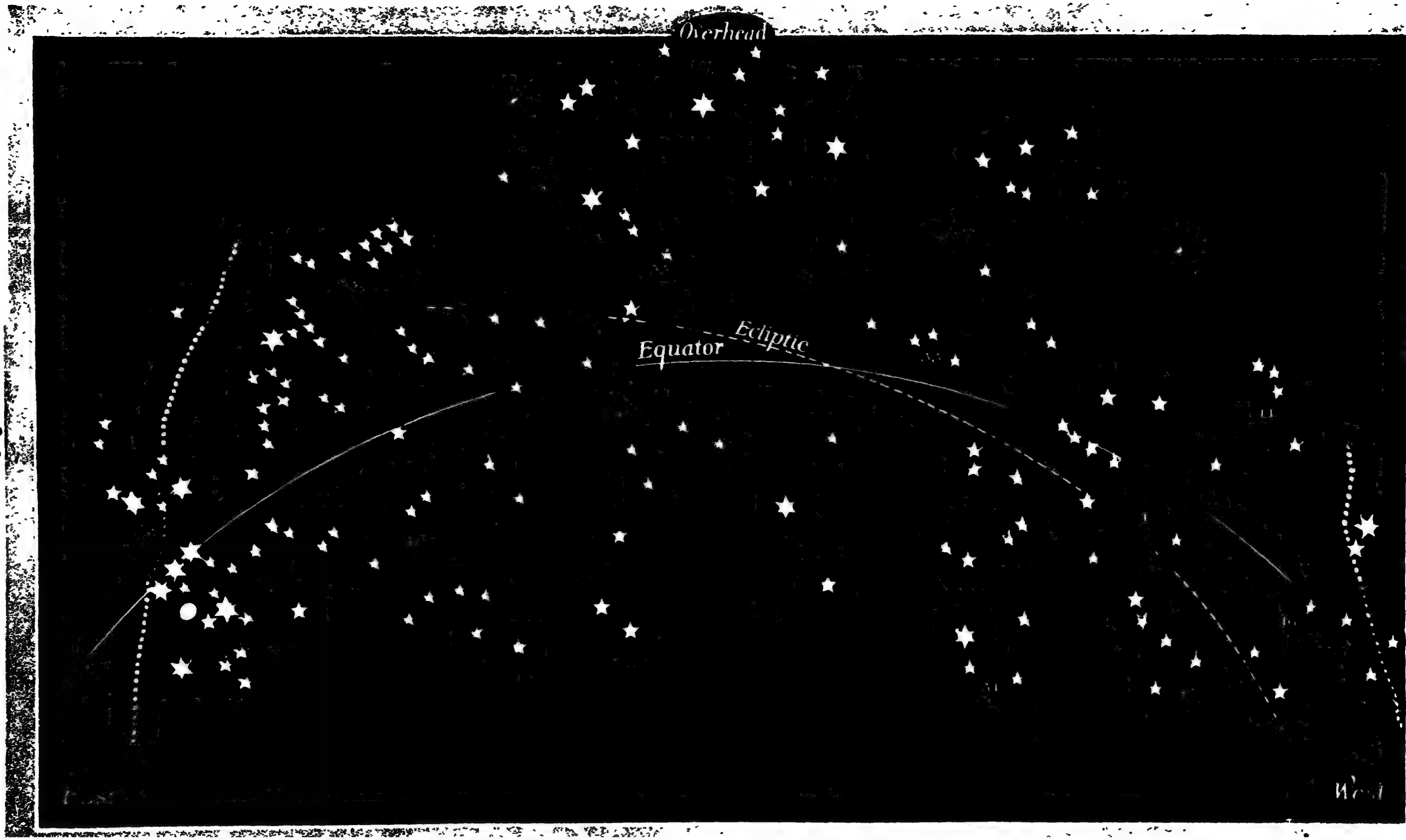
On an evening in July or August the northern sky contains these constellations: 2. Andromeda. 3. Boötes. 8. Cassiopeia. 9. Cepheus (se'fus). 10. The Charioteer; bright star, Capella. 15. The Dragon. 17. Hercules. 18. The Lion. 21. The Lyre; big star, Vega 26. Pegasus. 27. Perseus; large star, Algenib. 32. The Swan; large star, Arided. 35. Ursa Major, the Great Bear, or the Big Dipper, with the two pointers, one in the middle of the back and the other just below it; these always point to the Pole Star. 36. Ursa Minor, the Little Bear, or the Little Dipper, with the Pole Star on the tip of its tail.



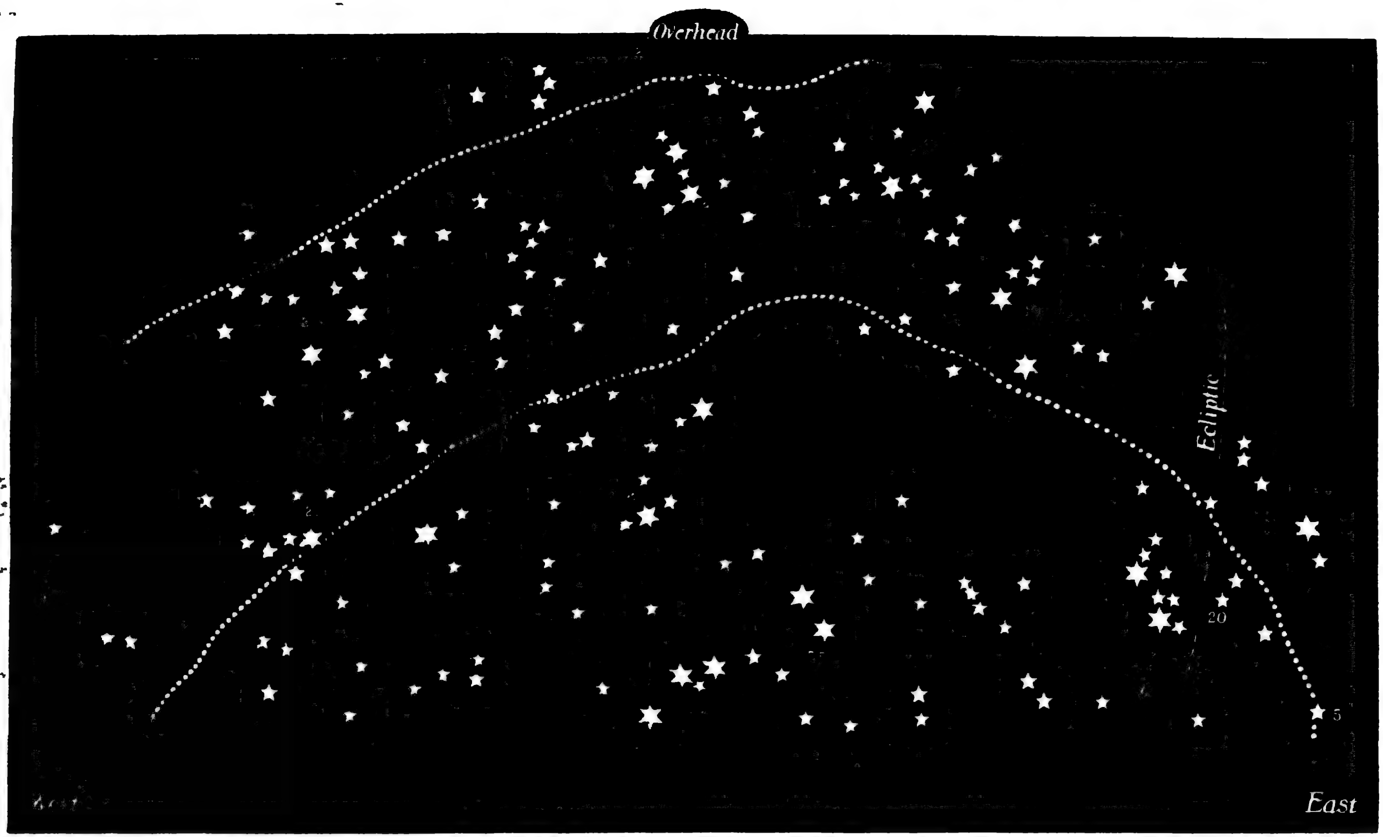
The southern sky on an evening in September or October shows these constellations: 1. Aquarius, or the Water Carrier. 2. Andromeda. 7. Capricornus, or the Goat. 14. The Dolphin. 16. The Eagle; bright star, Altair. 21. The Lyre; white star, Vega. 24. The Man with the Serpent. 26. Pegasus, with its four bright stars forming "the square of Pegasus." 29. Sagittarius, or the Archer. 31. The Southern Fish; star at tip of nose, Fomalhaut (fō'măl-hôt). 32. The Swan. 33. Pisces, or the Fishes. 38. The Whale; large star in tail, Diphda. Since the planets are constantly changing position, it is of course impossible to show them.



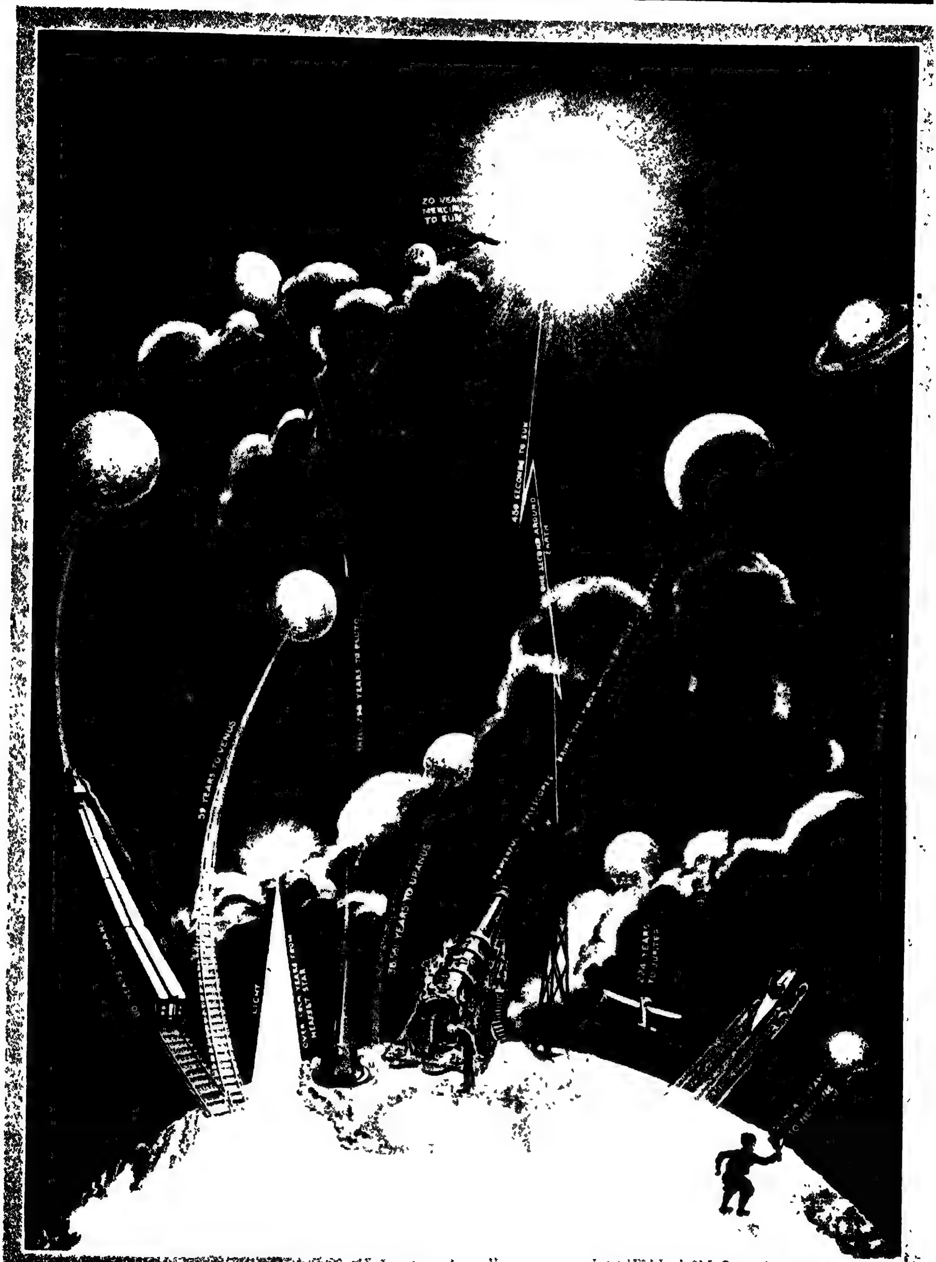
Looking north into the evening sky in September or October, you will see these constellations 2. Andromeda 3 Bootes 8 Cassiopeia 9 Cepheus 10 The Charioteer, bright star, Capella 13 The Crown 15 The Dragon 17 Hercules 21 The Lyre, big star, Vega 27 Perseus, big star, Algenib, star in Medusa's Hair, Algol 28 Aries, or the Ram, big star, Hamal. 32 The Swan, big star, Arided 34 Taurus, or the Bull, with the star group called the Hyades and the bright star Aldebaran 35 The Great Bear, or Big Dipper 36. The Little Bear, or Little Dipper, with the Pole Star at the tip of its tail.



These are the constellations seen in the southern skies on an evening in November or December: 1. Aquarius, or the Water Carrier. 2. Andromeda. 7. Capricornus, or the Goat. 14. The Dolphin. 16. The Eagle. 22. The Hare. 25. Orion; big star under arm, Betelguese; on uplifted heel, Rigel; band of bright stars, Orion's Belt. 26. Pegasus. 28. The Ram. 31. The Southern Fish; large sta Fomalhaut. 33. The Fishes. 34. The Bull; big star at eye, Aldebaran; star grou in head, the Hyades; star group in back, the Pleiades. 38. The Whale; star i tail, Diphda; at back of mouth, Mira. 40. The River.



These are the constellations seen in the northern skies on an evening in November or December: 2. Andromeda 5. The Little Dog large star, Procyon 6 Cancer, or the Crab 8 Cassiopeia 9 Cepheus 10 The Charioteer, bright star, Capella 15. The Dragon 16 The Eagle 17 Hercules 20 The Twins bright star in head of twin at left, Pollux, star in head of twin at right, Castor. 21 The Lyre; bright star, Vega 27 Perseus, star at waist, Algenib, in Medusa's Hair, Algol. 32 The Swan large star Arided 35 The Great Bear, or Big Dipper 36. The Little Bear, or Little Dipper, star at tip of tail, the Pole Star



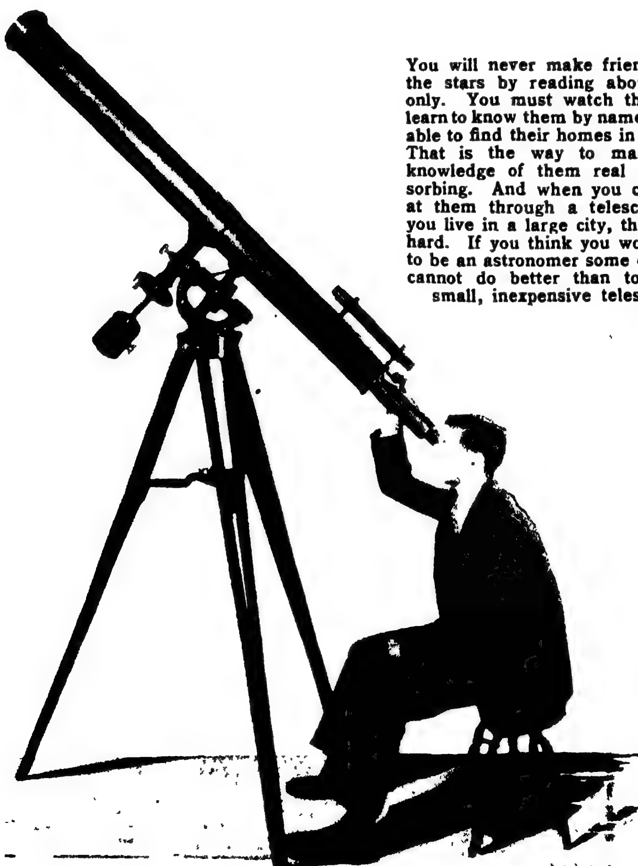
If you will examine this diagram closely, you may be better able to form some notion of the tremendous vastness of the universe. You will notice that our swiftest conveyances—express trains, automobiles, and airplanes—hardly make an impression on those terrific distances, even when they go at topmost speed. Sound and radio waves do better, though the boy who feels he is making a lively disturbance with his gong, will not live long enough for its noise to carry to some of the nearer planets. The swiftest thing in the universe is a ray of light—it is literally as quick as thought! Yet the rays from the nearest star, the one we know as Alpha Centauri, the brightest star in the constellation of the Centaur, are four years in reaching us.

ceeded to the honor. The reason for this change is that the earth—just like a top or any spinning object—tends to wobble as it spins. The wobbling causes changes in many of our reckonings. For instance, the sun now arrives at the various points in the zodiac about a month ahead of the time it was accustomed to arrive when the ancients first named the constellations in the gigantic belt. This change is known as the "precession of the equinoxes."

We have told only a little about the faithful lights that have shone for millions of years and will shine for millions more when you and I are gone. But all your life you wil' be learning more about them—and all your life you will be more and more amazed at the marvels of their size and beauty. And sometimes you will say, with the great philosopher Kant, that there are just two marvels in the universe—the starry heavens above, and the mind of man below. But sometimes your own mind will be so overwhelmed by the vast scheme of the sky that you will cry out with a greater poet than Kant:

"When I consider thy heavens, the work of thy fingers, the moon and the stars, which thou has ordained;

"What is man, that thou art mindful of him? and the son of man, that thou visitest him?"



You will never make friends with the stars by reading about them only. You must watch them and learn to know them by name, and be able to find their homes in the sky. That is the way to make your knowledge of them real and absorbing. And when you can, look at them through a telescope. If you live in a large city, this is not hard. If you think you would like to be an astronomer some day, you cannot do better than to buy a small, inexpensive telescope.

Photo by American Museum of Natural History

Reading Unit No. 10

THE "CLOUDS" IN STARRY SPACE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What are nebulae? 1-182
When do nebulae become visible? 1-182
What is the nature of the bright nebula in Orion? 1-182-83
What is the Milky Way? 1-183
What are planetary nebulae? 1-183
What are "island universes"? 1-183
What is a light year? 1-183
About how many nebulae may be visible through a large telescope? 1-183

Things to Think About

How far away from the earth is a nebula if its light takes 1,000 years to reach us?
How large is the nebula of Andromeda if light takes 50,000 years to cross it?
How is it possible to see a nebula that has gone dark?
How do some nebulae prevent us from seeing certain stars?

Picture Hunt

Describe the characteristics of a nebula. 1-182
Why are observatories built mountain tops? 1-183

Related Material

What is the nebular hypothesis? 1-5-6
According to this hypothesis, how may the solar system have evolved from a nebula? 1-4
How are astronomical telescopes built to view nebulae? 1-185-86, 188-89
How may the composition of a nebula be determined? 1-187, 440-41
Why are the nebulae invisible in daylight? 1-175-76, 426
How do we measure the speed of light coming to us from heavenly bodies? 1-417
How may we see some nebulae by reflected light? 1-182, 422
How do scientists decide where to put astronomical observatories? 1-183, 190

Leisure-time Activities

PROJECT NO. 1: Construct a model of an astronomical observatory tower, 1-183.
PROJECT NO. 2: On a clear moonless night, locate some nebulae with the aid of field glasses, 1-182-83.

Summary Statement

Scattered through the sky are thousands of patches of light called nebulae. Many represent universes larger than our own.

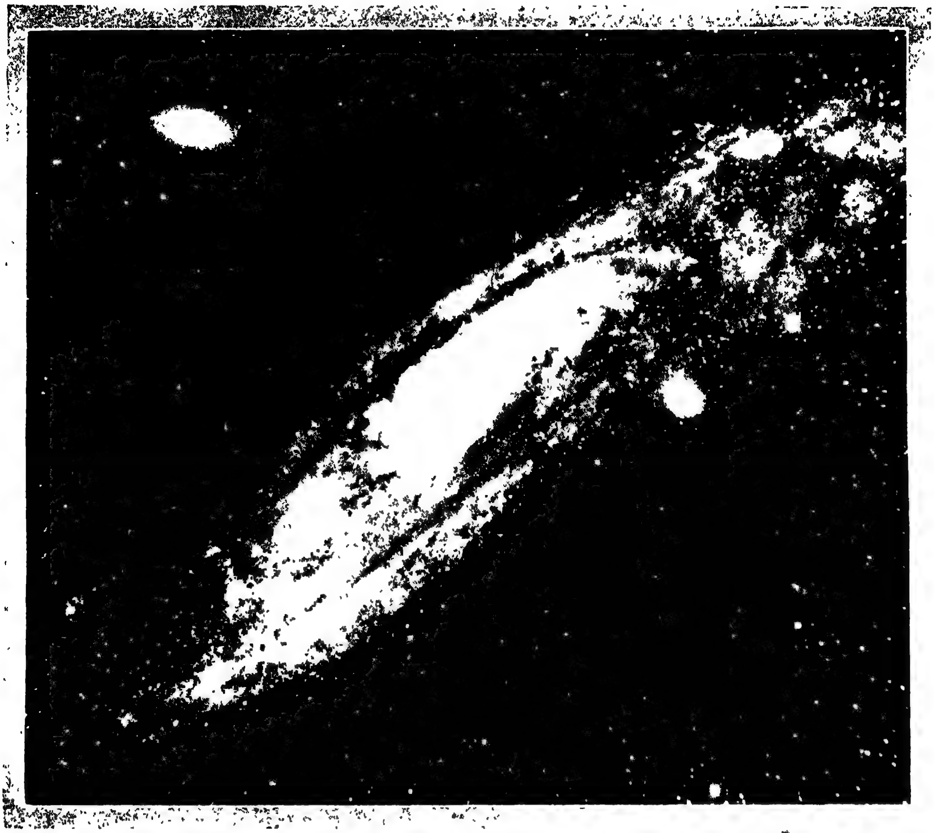


Photo by Yerkes Observatory

In the constellation of Andromeda is this great starry mass, or "nebula," so far away that its light takes almost a million years to reach us. That great cloud of suns, many of which must be as bright as our own or perhaps a thousand times brighter, is only one of many similar universes in the heavens.

The "CLOUDS" *in* STARRY SPACE

Some of Them Are Glowing Masses of World Stuff Far Out beyond the Boundary of Our Universe

SCATTERED abroad through the sky are thousands of faint patches of light, two of which are bright enough to be seen by the naked eye. They are called "nebulae" (nĕb′ū-lē), from a Latin word for "cloud"—the singular is "nebula" (nĕb′ū-lȧ). On any clear moonless night you may see one for yourself in the sword handle of the constellation of Orion (ō-rī′ŏn) or in the constellation we call Andromeda (ăn-drŏm′ē-dȧ). They look like faintly gleaming mists.

Such glowing "clouds" come from very different causes. Some of them are mere masses of gas and dust spread out for millions of miles through space. If they have no way of catching light and reflecting it back to us, they look like great dark holes in the fabric of the sky, for they are dense enough to put out the light of the stars that are behind them, though sometimes a handful of stars may be sown against their inky background. But when they can catch the light from stars that are near, they gleam

with a mysterious glory that is spread over millions of miles of space. Such is the famous nebula in Orion. Most of them are in the Milky Way.

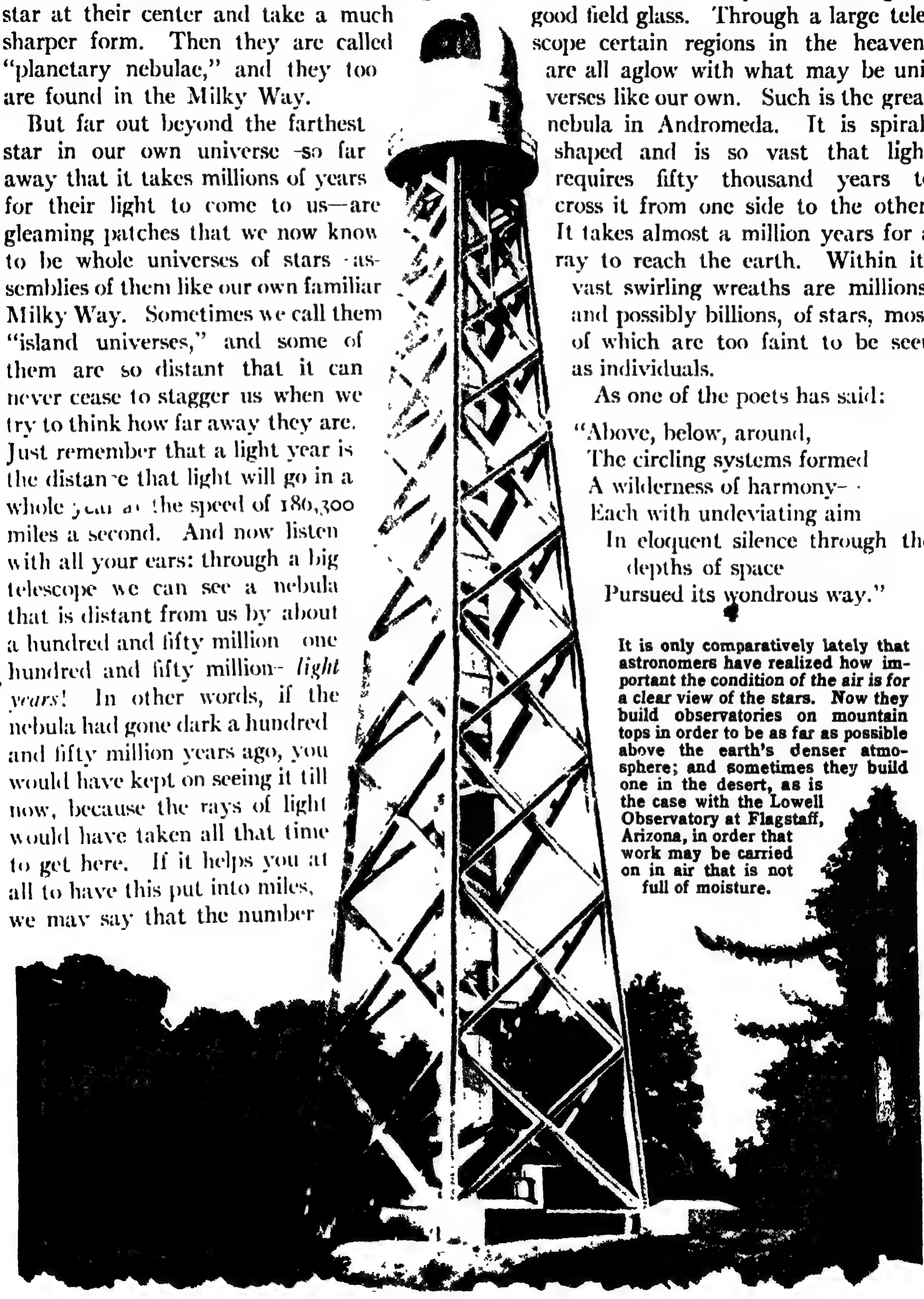
Sometimes such fire mists have a bright star at their center and take a much sharper form. Then they are called "planetary nebulae," and they too are found in the Milky Way.

But far out beyond the farthest star in our own universe—so far away that it takes millions of years for their light to come to us—are gleaming patches that we now know to be whole universes of stars—assemblies of them like our own familiar Milky Way. Sometimes we call them "island universes," and some of them are so distant that it can never cease to stagger us when we try to think how far away they are. Just remember that a light year is the distance that light will go in a whole year at the speed of 186,300 miles a second. And now listen with all your ears: through a big telescope we can see a nebula that is distant from us by about a hundred and fifty million—one hundred and fifty million—*light years*! In other words, if the nebula had gone dark a hundred and fifty million years ago, you would have kept on seeing it till now, because the rays of light would have taken all that time to get here. If it helps you at all to have this put into miles, we may say that the number of miles to this nebula is nearly 1,000,000,000,000,000,000,000.

Maps and photographs of the sky show over fifty thousand nebulae, some few of which can be seen fairly well through a good field glass. Through a large telescope certain regions in the heavens are all aglow with what may be universes like our own. Such is the great nebula in Andromeda. It is spiral-shaped and is so vast that light requires fifty thousand years to cross it from one side to the other. It takes almost a million years for a ray to reach the earth. Within its vast swirling wreaths are millions, and possibly billions, of stars, most of which are too faint to be seen as individuals.

As one of the poets has said:

"Above, below, around,
The circling systems formed
A wilderness of harmony—
Each with undeviating aim
In eloquent silence through the depths of space
Pursued its wondrous way."



It is only comparatively lately that astronomers have realized how important the condition of the air is for a clear view of the stars. Now they build observatories on mountain tops in order to be as far as possible above the earth's denser atmosphere; and sometimes they build one in the desert, as is the case with the Lowell Observatory at Flagstaff, Arizona, in order that work may be carried on in air that is not full of moisture.

Reading Unit No. 11

EYES THAT SWEEP THROUGH SPACE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the astronomer's workshop? 1-185

How may the moon be brought to within 50 miles of us? 1-185

What is a spectrum? 1-187

What do astronomers know about the composition of stars? 1-187-88

How is an eclipse recorded? 1-188

How does a planetarium bring the stars "indoors"? 1-190-91

The great astronomers, 1-191

Things to Think About

How is the spectroscope's "rainbow" read to tell us the composition of heavenly bodies?

Do the stars rise and set? Are they motionless?

How do observatories at great altitudes overcome the twinkling of stars?

How may a camera be used at the eyepiece of a telescope?

Picture Hunt

How does a telescope follow a star as the earth rotates? 1-186

How is an observatory constructed to enable the telescope to follow the stars? 1-188

Related Material

How did Einstein's theory of relativity change the science of astronomy? 13-409

How does the spectroscope tell us the composition of matter? 1-440-41

How is the telescope used to check the accuracy of our clocks? 1-186, 10-459-73

How did Galileo's telescope differ from the modern instrument? 13-396-97

How are the principles of lenses and mirrors used in astronomy? 1-422-34

Practical Applications

How is the spectroscope used to determine the composition of substances on the earth? 1-187

How do the stars tell us the correct time? 1-186

Leisure-time Activities

PROJECT NO. 1: Make a rainbow, 1-187.

PROJECT NO. 2: Take time-exposure photographs of the sky at night. If possible, attach the camera to a telescope, 1-190.

Summary Statement

The telescope, spectroscope, and camera are the astronomer's tools.

Joseph von Fraunhofer is here shown exhibiting one of his remarkable optical instruments. This German optician and scientist discovered the dark lines which we see in a ray of sunlight when it is passed through an instrument called a spectroscope. Those lines tell us what substances are present in the sun or in a star millions of miles away, and are called the Fraunhofer lines, after their discoverer.

EYES THAT SWEEP *through* SPACE

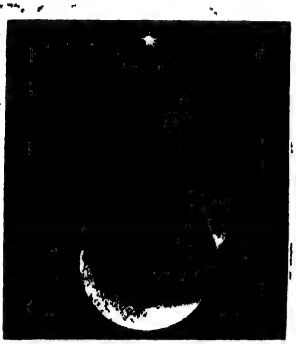
And Some of the Other Instruments That We Now Use for Finding Out the Secrets of the Stars

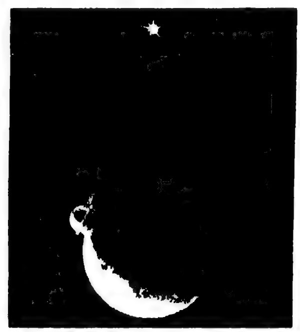
IN OLDEN days a man had nothing but his eyes to watch the stars with, and of course he could not be expected to see very much. It is since we have had telescopes and other modern instruments that we have found out most of the secrets of the stars. Without their help we should be just about where our ancestors were three hundred years ago.

The workshop of an astronomer is known as an observatory (ŏb-zûr′vȧ-tō-rĭ). Here are all the beautiful and delicate instruments by which he learns of bodies trillions of miles away. The cost of the instruments is stupendous, and their powers are so varied as to make them seem almost magical. The most important are the telescopes for any well equipped observatory will have more than one. The large or "equatorial" telescope, used for taking general observations and sometimes strong enough to bring the moon as near as twenty-four miles, is placed under a protecting dome in which a shutter opens wide enough to show the sky from the horizon well beyond the point directly overhead. The whole dome can

be made to revolve, so that the opening may be turned toward any point in the heavens.

Because the earth turns constantly, a star seen through a telescope will soon swim out of view; that is to say, the telescope turns with the earth and so must be continually adjusted if a given star is to be kept in sight. This could be done by hand for all ordinary purposes, although the telescope often weighs many tons; but sometimes, as when stars are being photographed —a process that may cover everal hours—the movement of the telescope must be perfectly timed to keep pace with the turning of the earth. Otherwise, the star would appear, not as a clear image, but as a streak of light across the plate; for if the camera moves, the effect is quite the same as if the object itself had been moving. All this is remedied by turning the telescope evenly by clockwork, so that it may be kept pointing at exactly the same spot in the heavens. These clocks, like all the other instruments, are adjusted with marvelous exactness.





Though the stars seem to us to rise and set, they really are always in the same place in the heavens. It is we who move, as the earth spins round beneath them. This constant change in our position makes it necessary for a telescope to be always shifting if it is to keep a given star in view. These three pictures will show you very clearly just what takes place. The one on the left shows a telescope directed at a star early in the evening. As the night wears on, the star is higher and higher overhead, until it reaches its highest point in the heavens. Then it begins to go down the sky toward the horizon, and the telescope must point in quite the opposite direction from the one it pointed in at first.

The Transit of a Star

In nearly all observatories there is a much smaller telescope known as a "transit instrument," and used for watching the transit —or passage—of a star or other heavenly body across a very fine wire in the eyepiece. *Often this "wire" is in reality a spider's* web. Usually there are several such threads, or "wires." To watch a star pass across these lines is an interesting experience; it gives one a startling proof that we are being carried swiftly through space on a whirling planet.

A Clock That Keeps Star Time

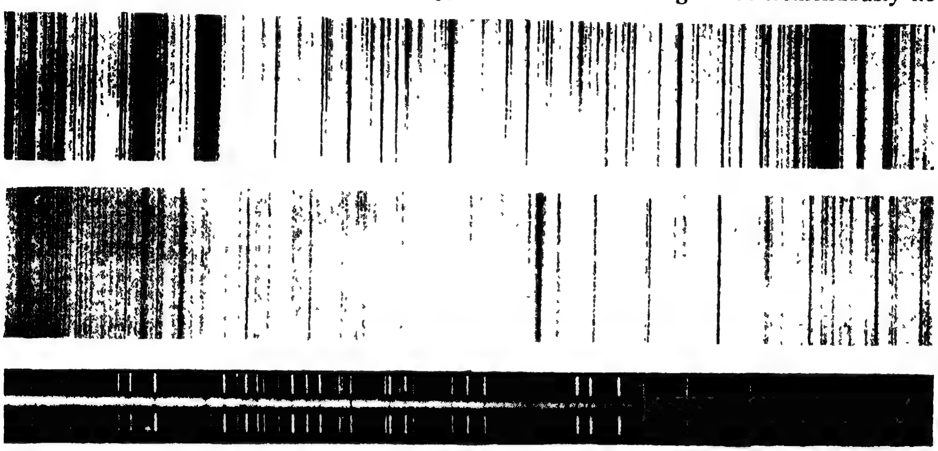
In some observatories star transits are carefully photographed. The astronomer has a catalogue of the stars which tells him, to the fraction of a second, when certain stars are due to pass his "wire." Just before the time when they should cross it, he takes up his position at the instrument and checks his sidereal clock as the star swings by.

"And what," you say, "is that kind of clock?"

If you will look in the dictionary you will find that the word "sidereal" (sī-dē′rē-ăl) comes from a Latin adjective meaning "pertaining to the stars" for "sidus" is the Latin word for "star." A sidereal clock is, therefore, a "star clock" —one that is regulated by the stars and not by the sun. It is the kind that is used for all astronomical work, and, interestingly enough, its time differs considerably from that of our ordinary clocks. In fact, the day by star time is almost four minutes shorter than the day as measured by our clocks.

Curiously enough, it is easier to sit in London or New York and tell what sub-

stances go to form a star trillions of miles away than it would be to tell what substances are to be found on a lonely island in the southern seas. Yet the island, in comparison with the star, is almost under foot. Now this is all because there is no way to investigate the island without going out to see it, but in the spectroscope (spĕk'trô-skōp) the ray from the most distant star can be made to tell just what is in the star. The spectroscope reads the secrets in the light no matter how far the light may have come.



When a ray of sunlight is passed through a spectroscope, it comes out in a long colored band like the rainbow. Two different sections of this band—which is called a spectrum—are shown in the two upper bands shown above—of course without the colors. The dark lines are the famous Fraunhofer lines, which show what substances are present in the sun. At the bottom is the spectrum of a dwarf star.

How to Make a Rainbow

When a beam of light passes through a triangular piece of glass—or what is called a prism (prĭz'm)—a curious and beautiful sight is the result. The beam is split up into all its different parts and comes out on the other side of the prism in seven different kinds of rays. In other words, it is turned into a rainbow, and appears in the shape of seven brightly colored bands—violet, indigo, blue, green, yellow, orange, and red. You can always recall their order if you will memorize the imaginary word "vibgyor." These seven parts of which the sun's light is composed are called its spectrum (spĕk'trŭm). They may be seen in the rainbow as well as in a prism, for the millions of drops of water through which the sun's light passes whenever we see a rainbow in the sky act in precisely the way a prism does.

Now every kind of light has its own spectrum—that is to say, its own peculiar arrangement of bands of color when it is passed through a prism; and every different kind of chemical substance sends out a different kind of light. A tremendously hot solid or liquid substance or a hot gas under high pressure all send out light which forms a band of colors without a single break; this is called a "continuous spectrum." But a flame gives a spectrum broken by bright lines across its width, and from their position we can tell what substances are being burned.

What Stars Are Made Of

In light that comes to us from the sun or from a star these bright lines become black, though their arrangement is the same. They are dark because the cooler, outer layer of the ball absorbs the light from the inner, hotter, substances and leaves a blank, which appears as a break in the spectrum where ordinarily the bright bands would be. We know this as a "discontinuous spectrum"; it in no way interferes with our ability to tell what kind of light it is we are examining. For instance, when dark lines appear in a certain position in the yellow part of the spectrum, we know that sodium, a common substance in chemistry, is present in the

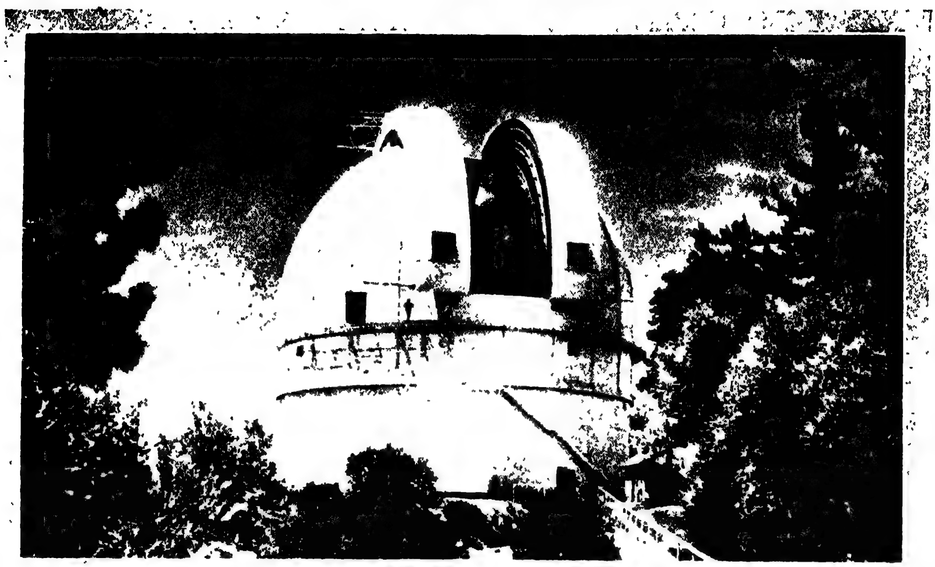


Photo by Mt Wilson Observatory

This is a view of the outside of the Mt. Wilson telescope. As you see, portions of the dome may be opened, in order that an observer may see every quarter of the heavens simply by revolving the telescope.

star, for whenever we burn sodium in a flame we always see this particular arrangement of lines. Some substances produce a great number of lines; for instance, iron and calcium yield many hundreds. Chemists have made up charts of all the spectra of the different substances; so we may recognize them even though the substance is sending out the rays to us from the most distant star.

The Wonderful Spectroscope

The instrument by which the spectra—plural of "spectrum"—are detected is called a spectroscope. Its principle is simple enough. Its most important part, of course, is a glass prism. This is placed at one end of a long tube, which is so devised as to admit only a very narrow beam of light at the other end. After passing through the prism, the light travels through another tube similar to the first and appears before an eyepiece at the end. It is here that the spectrum may be viewed.

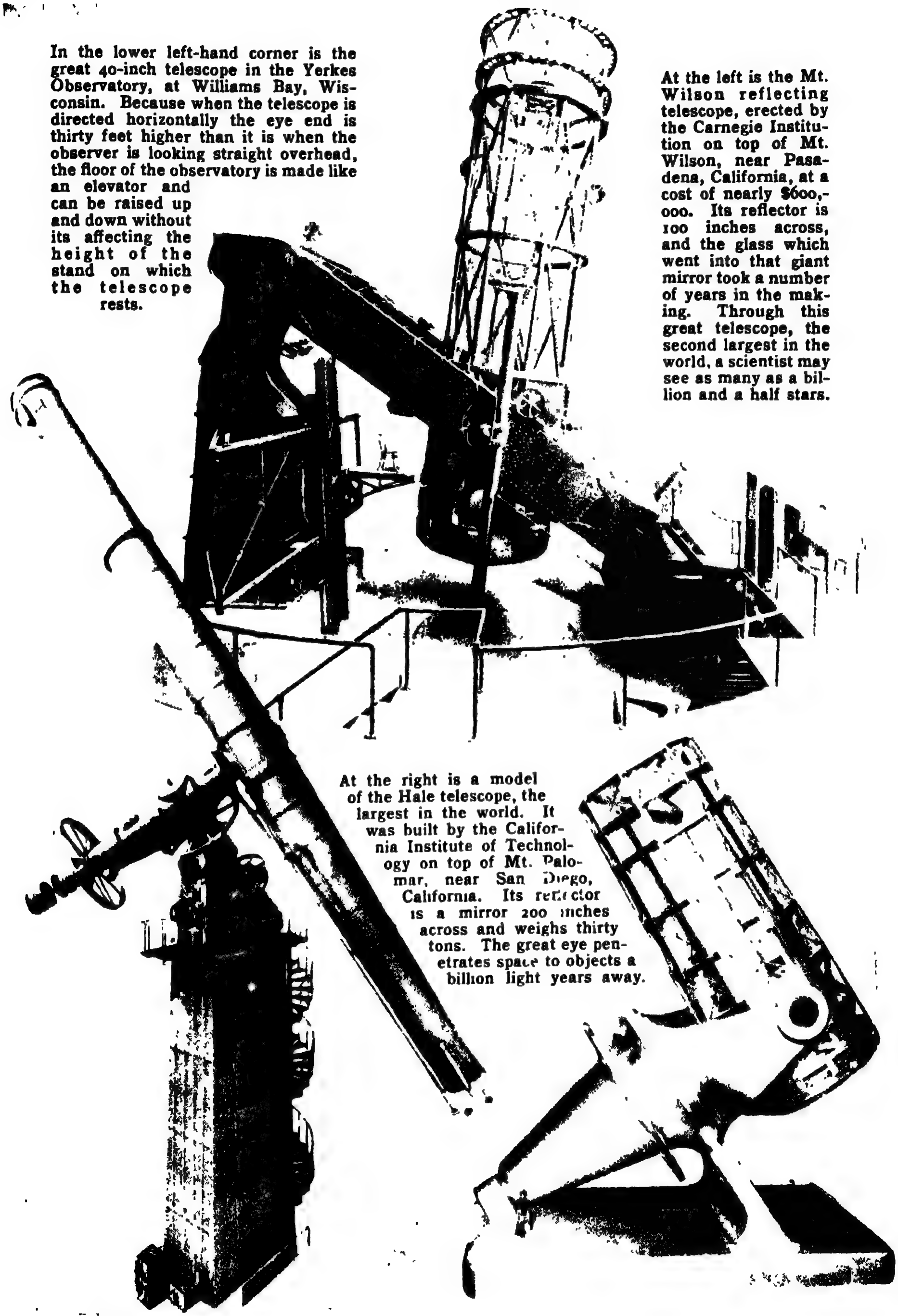
It is usual, in studying the stars, to take photographs of the spectra and examine them later. A photograph possesses the great advantage of recording lines which are altogether invisible to the naked eye.

Modern scientists also have an instrument called a thermocouple to measure a body's temperature. It might be said to "see" the heat rays.

It is not, after all, so very long ago that a total eclipse of the sun, lasting a few precious seconds, could come and go and leave no lasting record. A memory in the minds of a few astronomers, impressions gathered during the excitement of the great event, were the only records science had to work upon. To-day all this is changed. In accord with plans made months in advance, hundreds of delicate cameras are trained upon the spectacle. When the full light of day returns once more, the photographic plates contain a lasting record of everything that happened. These the astronomer may study as long as he pleases; the facts they show are there beyond debate.

The Magic Eye of the Camera

And all this is useful for yet another reason. The camera has a much keener eye than man. When the human eye has looked intently upon an object for a few seconds, its delicate tissues grow tired and must be rested; but



In the lower left-hand corner is the great 40-inch telescope in the Yerkes Observatory, at Williams Bay, Wisconsin. Because when the telescope is directed horizontally the eye end is thirty feet higher than it is when the observer is looking straight overhead, the floor of the observatory is made like an elevator and can be raised up and down without its affecting the height of the stand on which the telescope rests.

At the left is the Mt. Wilson reflecting telescope, erected by the Carnegie Institution on top of Mt. Wilson, near Pasadena, California, at a cost of nearly $600,000. Its reflector is 100 inches across, and the glass which went into that giant mirror took a number of years in the making. Through this great telescope, the second largest in the world, a scientist may see as many as a billion and a half stars.

At the right is a model of the Hale telescope, the largest in the world. It was built by the California Institute of Technology on top of Mt. Palomar, near San Diego, California. Its reflector is a mirror 200 inches across and weighs thirty tons. The great eye penetrates space to objects a billion light years away.

Photos by Yerkes Observatory, Mt. Wilson Observatory, and Wide World Photos

the sensitive photographic plate goes right on storing up impressions without a trace of weariness.

Where We Build Observatories

It also has the power of accumulating very faint impressions into something that may be seen. Many dim stars have been photographed which the eye of man has never seen. However long we may stare at an object too dim to be visible, we shall never see it; but the photographic plate can gather impressions over long hours. On careful development of the plate or film they will become visible. To-day astronomers seldom sit with their eyes glued to a telescope, as once they did. Instead, they take out the eyepiece and insert a photographic plate in its stead. Photography is thus a great aid to astronomy, and is one of the main reasons for the great progress of the science in the past few years.

It is hard to realize that people in a great city never see the stars in their full splendor. That is why the Hayden Planetarium, in New York City, gives joy to thousands. It contains over 9,000 stars, and can show the heavens as they looked upon that first Christmas night in Bethlehem nearly 2,000 years ago, or as they will look to-night or 2,000 years hence.

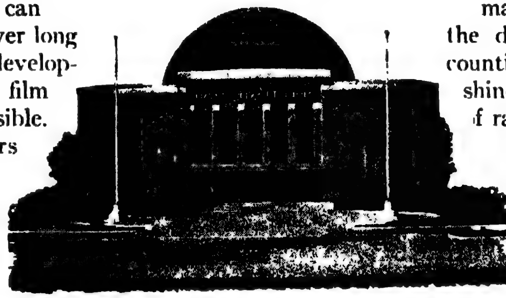


Photo by Carl Zeiss, Inc

The great blanket of air around the earth is not of even density, and as a ray of light passes through varying layers, it will quiver and twinkle. Naturally we find a twinkling light harder to study than a steady one.

Much of the twinkling is avoided if the observatory is built on a high mountain, for the light then has fewer layers to pass through. The air is also freer of smoke and particles of dust; and in many regions the fleecy, ever-changing clouds, which may be a great nuisance to a student of the heavens, are almost altogether left behind. But mountain tops alone do not insure "good seeing." Vegetation, snow, surrounding desert conditions, distance from the Equator, and the ease with which the point may be reached—all these affect the usefulness of a given spot as a situation for an observatory. They all are taken into consideration.

Many observatories now contain still other instruments—for registering earthquakes, estimating the strength and the direction of the wind, counting the hours of sunshine, recording the amount of rain, the temperature of the air at all times of the day and night, and the percentage of moisture that it contains—or what we call the humidity. Certain observatories even record the electrical conditions of the atmosphere.

When you know that "aqua" is the Latin word for "water" you are not surprised that an aquarium should contain water. And a planetarium (plăn′ē-tā′rĭ-ŭm), as you may guess, ought in some way to house the planets, though that would seem a hard thing to do. A dictionary will help us with a definition somewhat like the following: "an astronomical machine which represents the motions and the orbits of the planets; sometimes called an orrery." For the clever device was invented by the Earl of Orrery (ôr′ĕr-ĭ). It is housed in a building not unlike an Eskimo's hut in shape.

The Adler Planetarium, at Chicago, is the largest in the world. The dome is ninety feet across, and against it a multiple projector with 119 lenses can cast the image of 5,400 stars, each one natural in size and brilliance, and in its proper position in the heavens. In this way the whole drama of the skies may be shown to spectators, with sun and moon, the nebulae, and Milky Way. A lecturer explains what is going on as the artificial night walks across the planetarium's plaster sky.

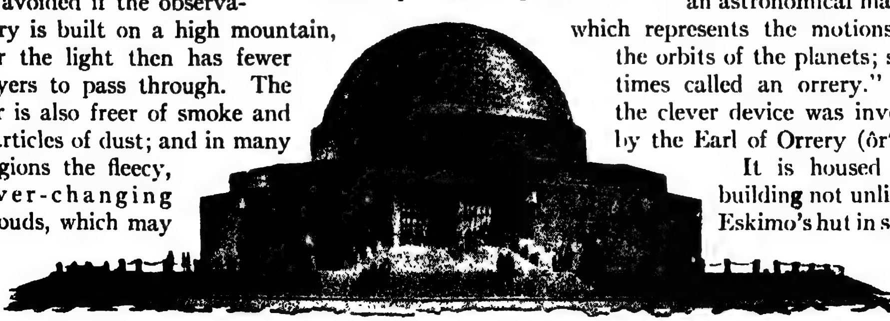


Photo by Carl Zeiss, Inc.

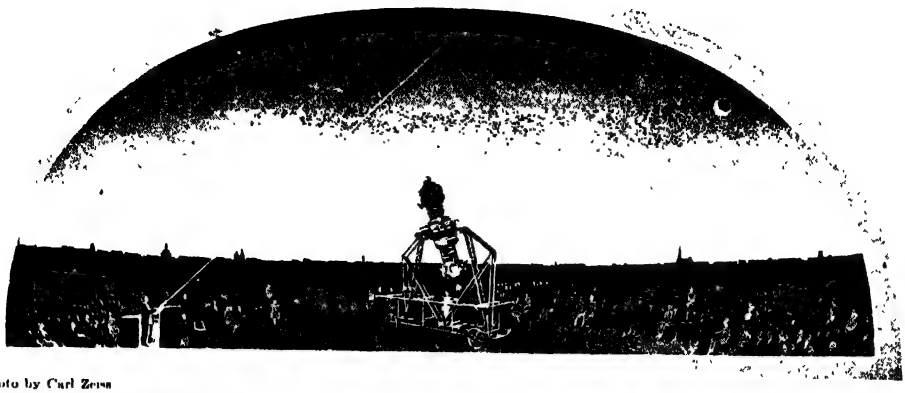


Photo by Carl Zeiss

Over the plaster dome of the planetarium the pageant of the starlit sky passes in slow procession. Meanwhile the lecturer, at the left, describing what takes place, points to the heavenly bodies with a finger of light.

Inside the domelike structure is a large circular theater, with rows of seats running all the way around the stage, which is set exactly in the center of the room. When we are settled comfortably in our places, the lights are switched off everywhere, except that enough are left to show a canvas which extends all the way around the bottom of the dome. On it are painted mountains and the shapes of lofty pines, all of them standing out as if against a distant horizon.

Suddenly a motion-picture machine begins to buzz, and immediately the ceiling is aglow with a thousand stars. We have the sense of gazing into the midnight sky. And now the moon peeps out above the horizon and all the heavenly bodies start to move across the sky. It gives one a curious start. The whole room seems to be turning over on its side. It is the moving stars that deceive us, just as at times when we are seated in a train that is standing in the station, we have the sense of moving off because a train on the next track has started slowly in the opposite direction.

By the time the moon has reached the point directly overhead, a soft light has begun to steal across the east. It is the sun. There on the horizon we see it rise majestically above the distant hills. Its light puts out the stars, which with the dawn had begun to fade. Automatic switches in the picture machine help the effect, which in the actual sky the sun achieves alone. Slowly he mounts and swings across the sky, just as he seems to do from day to day—though of course we know that in real life it is we who move and not the sun. He disappears into the western hills and twilight reigns again. We have come to the end of a planetarium day.

Then as we sit in the silence which the majestic pageant has laid upon us, we conjure up the picture of another great procession that we would gladly see. There they advance from far off in the East—a line of men with ardent gaze fixed on the glowing heavens. Their garments are not those we wear to-day. Their flowing beards and long, majestic robes speak of antiquity. For Asia, Egypt, Greece, and Rome—and many younger lands—have given some of their best sons to learn the secrets of the stars. As they draw near we recognize old friends. Brave Anaxagoras and Ptolemy pass by, arm in arm with a humble shepherd whose name we do not even know. Copernicus, Tycho Brahe, Kepler follow close behind. And then come Galileo and Sir Isaac Newton, discussing telescopes. In scores they pass before us, many of them men whose names have been forgotten. But great souls all, struggling often in the face of bitter opposition, and even at the risk of their lives, they labored patiently to solve one of the noblest problems of mankind—the secret of the universe.

Reading Unit No. 1

HOW THE WEATHER MAKES HISTORY

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is meant by climate? 1–193

How does the Negro's color help him to withstand certain climates? 1–194

What is one explanation as to why the northern races are white? 1–194

What is believed to be a cause for migrations? 1–194

Why did the Spaniards settle South America? 1–194

Why were the English able to settle in New England? 1–194

Why did Eskimo civilization remain primitive? 1–195

Why do the natives of tropical jungles remain uncivilized? 1–196

Things to Think About

How does weather affect civilization?

What conditions on the earth's surface would be necessary in order to produce unchanging weather?

Why have certain great cities vanished?

How has weather been the cause of war?

Related Material

What is the work of the United States Weather Bureau? 1–275-78

What are the seasons for plant growth? 1–211, 2–195-96, 256

How is temperature measured? 1–207-8

How doe climate affect the clothes worn by people? 9–12, 16

How does climate affect language? 10–3

What is the animal life of the Antarctic? 4–204, 217-18, 223-24, 332, 335, 13–504-5

Practical Applications

How do people in different climates protect themselves against the weather? 1–195-97

How do people in temperate climates maintain a food supply when plants are not growing? 1–196

Leisure-time Activities

PROJECT NO. 1: Collect and mount pictures and photographs of the clothing worn in different climates.

PROJECT NO. 2: Construct models of houses used in different climates, 1–196.

Summary Statement

Weather has changed the course of history because it has forced man to seek food and shelter in adverse conditions.

We always think of men as living each one on his own little spot of earth and calling it home. But if we could see with the eye of history, we should think of mankind as ceaselessly on the move, always pushing on into some new land, always leaving the old and seeking the new. And one of the chief forces that drive people about is the weather. The men in the picture above might well represent our race, chilled with rain and snow and beaten by the blast, yet always pushing on to greater comfort and freedom.

HOW *the* WEATHER MAKES HISTORY

We Have Learned How to Outwit the Weather, Though We Should Never Have Become Civilized Men without Its Whims

WHY are some people black and others white? Why do some live mainly on fish, others on fruit, and others on flesh and cereals? Why do some build towering cities while others are satisfied with scattered huts? There are a good many different answers to all these questions, but at bottom many of them come down to the fact that it is because of the weather! Or perhaps it would be better to say because of the climate, for "climate" means all of the changes of weather a given spot may have.

Now of course we are all used to having our own affairs affected by the weather. Often a rain has upset our plans for an outing or a picnic. Some of us may have broken a bone on an icy day—and we all have heard of houses struck by lightning or of men lost in a blizzard. Only listen to people talk and you will see how much they think about the weather!

But it is not only your plans and mine that are disturbed in this way. The weather has upset the lives of whole nations. It has rearranged the map. It has made history. And without the changes it has brought about, you and I should not be living where we live to-day. We should not look as we look or act as we act. Yet "weather" only means the state of the atmosphere from one day to another or one season to the next.

For it has even given us our color! In lands where the heat is intense and the sun beats mercilessly down twelve months in the year, even the fairest skins grow tanned. And after long centuries the whole race turns dark. It takes on a lasting coat of

tan that protects it against sunburn. So natives of regions that lie along the Equator are dusky brown or black, while the races that live farther north have skins that are fairer. For the men of the north not only see less of the sun but are usually indoors so much that they do not need a coat of tan to protect them. They are the white races, and they often have blue eyes and yellow hair. It was the weather that made them so.

Nature has been too kind to this happy-go-lucky mother of the Tropics. Can you imagine her living in London or New York?

To her Eskimo children Nature is a very stern mother indeed. This Eskimo woman will have to sit in the cold for hours, waiting to catch a meal of fish through a hole in the ice.

Photos by American Museum of Natural History and International Harvester Co

To her children of the Temperate Zone Nature is a firm but kindly parent—the best sort to have. So there men lead busy, interesting, comfortable lives, and civilization flourishes. Food is not too easy to get—and not too hard!

Often, too, it was the weather that sent their forefathers into the land in the first place. For ever since man has been on the earth he has been driven about by dry weather or flood or frost. Whatever disturbed his supply of food has sent him wandering. Sometimes a whole tribe, roused by hunger or thirst, have snatched up their arms and gone forth to murder and rob—a war has been caused by the weather! And sometimes the hungering peoples have settled peaceably in new lands or with other nations. The races have mingled together and new races have been the result—and all on account of the weather!

We do not need to look far to see what the weather can do to civilizations. In the jungles of Central America are the ruins of Maya cities more than two thousand years old; and buried in the sands of the Gobi Desert are the bones of other dead cities that once had a throbbing life. It was the weather that killed them. In many cases, at least, it was some great and lasting change in moisture or temperature that drove the people away from their homes and changed their busy towns into crumbling, silent ruins, like bleaching skeletons.

Surely it was not an accident that led the sun-loving Spaniards to settle in the Tropics of the New World they discovered. They sought a climate more or less like their own at home—just as the English, used to cooler air and shorter summers, were willing to weather the winters of New Eng-

Photo Copyright by Stephen H Willard

It was the skillful fingers of the wind that carved these beautiful curves and masses. But few persons ever see them, for here in Death Valley, California, the climate is about as hot and dry as any in the world. So of course the place is a desert, with almost no rain and a heat that day afte day may climb to 120°F

land. Our own broad land is the result!

Let us hop off a little way into space and look at the earth through a telescope. We shall see at once that some parts of the earth are swarming with people, while other regions have not a single inhabitant; and it will be easy to guess that the places where the people live are those that have the climate that is best for man. But strangely enough, they will not always be the places where living is easiest—or where the climate is most comfortable.

Children of the Frozen North

For old Mother Nature seems to have arranged that we should thrive best when we have to work for a living. So climate has a great deal to do with character. To be sure, we need a certain amount of comfort. Neither men nor animals can live long in the midst of the blizzards that rage at the North and South Poles. And even outside the Arctic Circle the Eskimo has his hands full to keep himself alive. Wrapped in heavy furs, he takes his spear and crawls out of his hut of snow to hunt his food. He goes down to the frozen shore, climbs into his canoe, and paddles about all day among the ice floes looking for fish or seal. Fish, blubber -huge masses of fat—and the flesh of a few Arctic animals are about his only food. It is easy to see that he will have little time or inclination to build himself railroads and factories, or libraries, theaters, and schools.

Roving Arabs and Idle Africans

In deserts, too, life does not give men a chance to make the most of themselves. Even though the shifting soil may be rich, there is so little moisture that nothing will grow. So only two animals can cross a desert three or four days wide—man and the camel. The camel is built by nature to do so, and man has learned how. But the hardy Arab, whose wild, roving life takes him from watercourse to watercourse, is not likely to build up a fine music or poetry or architecture as he rides on the back of his camel.

But neither can the man for whom Nature does too much! In the hot forests along the Amazon are tribes who do not need to till the soil to get their food. They are the pampered darlings of our great Mother Earth. The land around them is rich and there is plenty of rain and warmth to make things grow all the year round. They do

not need warm clothing, or any other shelter than the thick foliage over their heads. As one writer puts it, "the natives lie flat on their backs and the bananas

One glance at these three homes will tell you in what section of the globe each one is to be found. The Eskimo makes his hut out of ice and snow because it is the only building material he has—and luckily for him, it is excellent to keep out the cold. But we know what would happen to such a house farther south when spring came along! Fortunately we have plenty of wood and stone to build our houses of. And because we are visited by the sun every day in the year, we can fill our walls with windows and doors, and live on spacious verandas. The Zulus in Africa find it much too hot for very heavy labor. So they just put up a hasty shelter against sun and rain, and build it of grass or leaves or whatever comes to hand. They don't intend to hand it down to their children.

Photos by American Museum of Natural History and Visual Education Service

drop into their mouths." So, like all spoiled children, they cannot do anything for themselves. Since they do not need to work or plan for a living, they never have learned how to work or plan for anything else. Their civilization is no higher than the Eskimo's. They are still savages because of their weather!

So it is in the Temperate Zones, between the icebound Poles and the blazing Tropics, that we find men at their best. There the earth will grow all the varied foods we need to make us strong, but we must work to raise them. For there is a season when the earth is frozen and bare; so we must spend the summer storing up food for the rest of the year. And we must build warm houses to shelter ourselves against the winter's blast. In other words, man must constantly use his wits to keep himself comfortable—and it is only by using his wits that he can develop them and so grow capable of building up a great civilization.

Before There Were Storms

Now it is an interesting fact that our good old earth never used to be tormented with all these fits of weather. For millions of years, before the crust of the earth was as rough as it now is, things were as calm and unchanging as a perfect summer's day. The seasons came and went without any great change in temperature, light breezes blew at times, and showers were frequent.

There were no "storms"—only settled "weather." To be sure, no man lived then to leave a carved inscription or printed book to tell us of the fact. We have to find it out from records left in the enduring rocks

Photo by Northern Pacific Ry

This is a scene from the land that sends us our cold north blasts, and this is the kind of scenery one has there all the year round. For though it is so many thousands of miles away, this great sheet of ice in Alaska helps to make the weather for people like you and me. The winds that blow over it make our weather colder; they bring us the clear, bracing days that act as a tonic. And in other ways those ice fields affect the lives of civilized men. For from time to time, with thunderous roar, a giant mass will break away, and as an iceberg go sailing down into warmer waters, perhaps to be the death of a gallant ship.

by the hand of Nature herself. But from them we can learn that whenever the earth's surface has been smooth—either covered with a broad ocean of water or lying in a low flat plain—the weather has been as gentle as a new-born lamb.

But the oceans were forced to recede when mountains began to raise up their great heads, and then the weather began to grow violent. For the air formed the habit of turning in great whirls sometimes more than a thousand miles across, and of scattering rain and snow as it twisted. And lightning began to play all about the earth's body, till now there are nearly two thousand thunderstorms flashing somewhere at any moment in the day.

It was not till things grew disturbed that man appeared. One wonders if he could have grown into the talented animal he is without this exciting variety in the state of the atmosphere. He might have been much like the South American natives we have just talked about—too lazy to do anything but eat and sleep. As it is, he is always busy shutting out the cold or getting in his food or providing clothes for his back. And when he has time enough left over, he will fill it with diverting sports and arts, in order to use up the energy he is now accustomed to spending.

So he will tell stories and paint pictures and play sweet music; he will invent hard games and delve into all branches of knowledge; he will swim the seas and climb the mountains and fly to the ends of the earth. And all this will be, in large part, because so much of the weather is uncomfortable!

Reading Unit No. 2

HOW THE SUN MAKES OUR CLIMATES

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What happens to plants when they lack sunlight? 1–199
What are the colors of sunlight? 1–199-200
How may the sun cure disease? 1–200
What kind of glass transmits the beneficial rays in sunlight? 1–200
Where does the sun go at night? 1–201
Where does daylight last for six months at a time? 1–201-2
What makes the weather? 1–201-2

Things to Think About

Why are the days and nights of equal length at Quito, Ecuador?
Why does the amount of sunshine that we get vary?
Why does the skin tan and freckle?
Why do the Tropics get the greatest amount of sunlight?

Picture Hunt

When it is summer in the Arctic, what is the season in the Antarctic? 1–199
What causes the seasons? 1–201
Where does the sun shine at midnight? 10–476

Related Material

What is the sun made of? 1–109
How does the sun supply energy? 1–341, 343-52
How is the sun's energy stored in coal? 1–343-46, 9–435
How does food provide us with energy from the sun? 2–366
What is meant by the midnight sun? 10–476
How does the sun affect the tides? 1–134
How has the sun affected art in Spain? 11–241

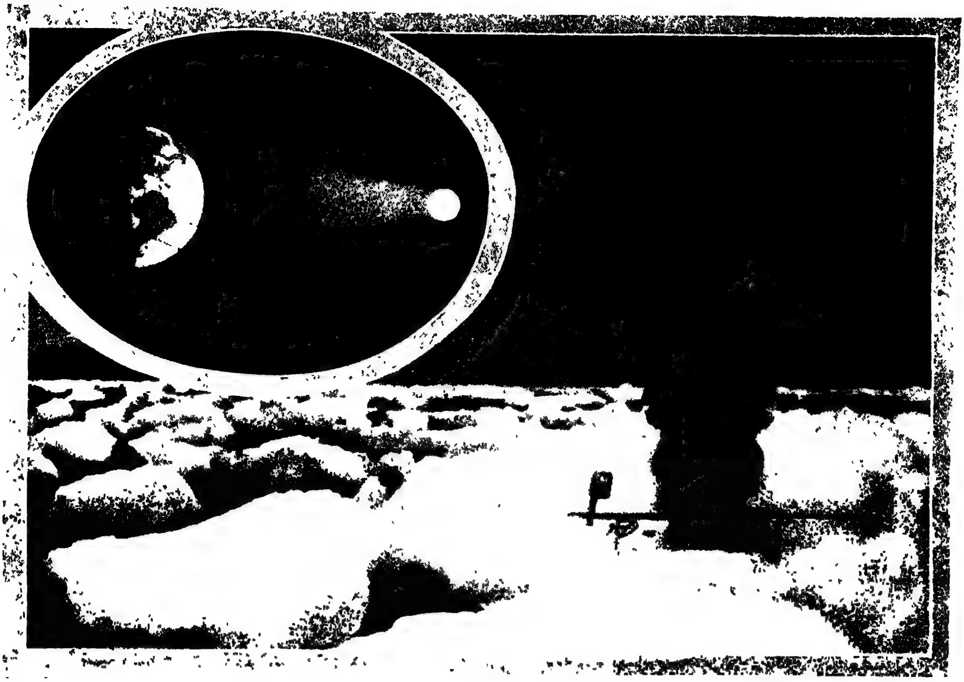
Practical Applications

How is sunlight used to improve health? 1–200
How should windows be made in order for us to get the fullest benefit from sunlight? 1–200

Leisure-time Activities

PROJECT NO. 1: Using a chandelier crystal, break up the sunlight into its different colors, 1–199-200.

PROJECT NO. 2: With the help of a friend, use a large ball or geography globe and a flashlight to show the course of the seasons, 1–203.



Here is an Eskimo fishing for seal. It may well be noon, but no sun is to be seen, for the chances are good that there is no sun in the sky. Only in the summer does he ever see the sun--and if you will look at the picture up in the corner you will see why that is. The earth is there shown with its North Pole tipped toward the sun—in constant daylight. The South Pole, you will see, is having its long night.

HOW *the* SUN MAKES OUR CLIMATES

A Few Hours of Sunshine Every Day Make All the Difference between Life and Death

HAVE you ever seen a potato that had sprouted in the dark? Its sickly shoots are pallid instead of a healthy green, and the unhappy plant soon dies. It cannot live without sunlight. And it is much the same with men. There is a deep reason why we like sunny weather. We may think, perhaps, that it is only because the sunshine makes us gay and the whole world beautiful. But under it all lies the fact that sunlight keeps us well and makes us vigorous. Without it plants die, as a rule; and the human race would die, too, if it had to live in the dark. We owe our very life to the sun.

What can it be in sunlight that is necessary to life? We cannot eat it or drink it. We do not even need it to keep us warm. Yet its magical rays keep all the world alive.

To answer the question we must first split a sunbeam into its various parts. Sunlight seems to be simply white, but really a ray of it contains all the colors of the rainbow, beautifully blended. Each one of the seven colors—violet, indigo, blue, green, yellow, orange, and red—may be sifted out from its fellows if the sunlight is passed through a prism (prĭz'm). This is a triangular piece of glass that casts the light in a series of colored bands very much like the rainbow. It can do this because each color travels in waves of a different length from all the rest; and when a sunbeam passes through the prism, each separate ray is

Photos by Miami News Service and Govt. of N. Z.

One might not suspect it, but all the patients shown above are taking their medicine, which consists of a dose of sunlight. In Miami, Florida, where this hospital is located, the sun is always high and warm, so its health-giving rays are used there in the treatment of all sorts of diseases. Those diseases the little Maori boy up in the corner is not likely to have. He lives in New Zealand, and basks in the sun all day long. Right now he is taking a bath in one of the hot pools of which New Zealand has so many.

bent by the glass according to the length of its wave. So we have all the colors spread out in a row before us. You may see them yourself if you hold a glass pendant from a chandelier between the sun and a sheet of white paper.

Why We Tan and Freckle

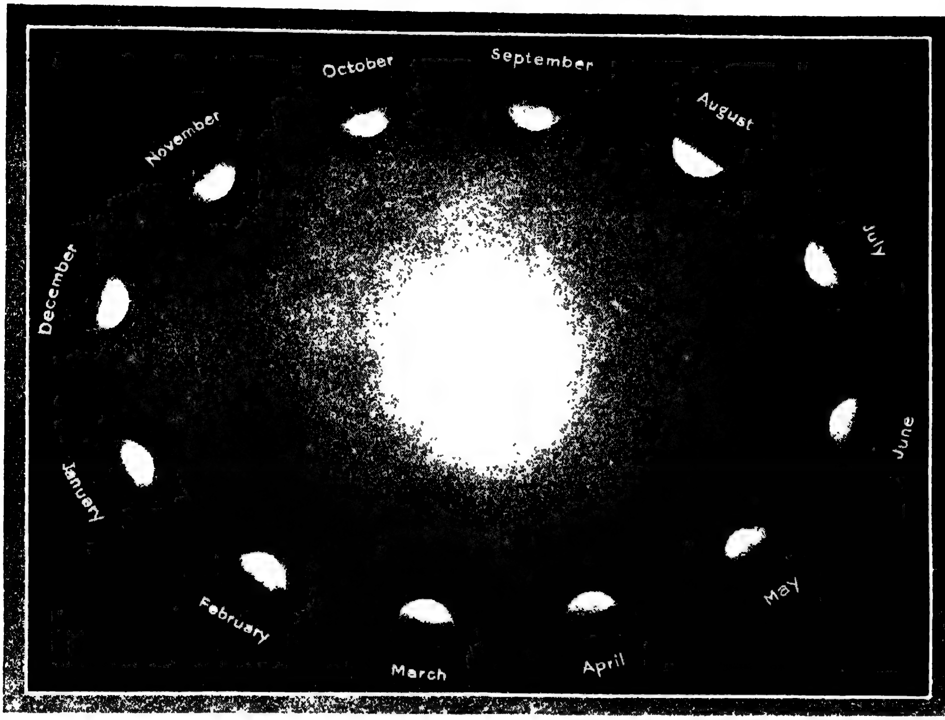
But while we see seven colors, there really are many more rays that the eye cannot see at all. These lie at each end of the rainbow—beyond the red and the violet. It is those on the end next the violet—we call them the "ultra-violet rays"—that have so much to do with health.

They have a powerful effect on the color of the skin, too. We all have been burned or have got a coat of tan from their action during the summer. For the skin, in order to keep from being blistered, protects itself with tiny particles of brown coloring matter that keep the rays out. Those particles are what make tan and freckles. In the same way, races that live in the Tropics, where the sun's rays are most powerful, turn permanently brown or black as a protection from the burning light.

Lately we have found out that many diseases may be helped by ultra-violet rays. So hospitals now have sun parlors for their patients. And since the magical light cannot pass easily through ordinary window glass, the windows of many sun parlors are filled with glass made of quartz crystal, through which the whole of a sunbeam comes freely.

How Long Does the Sun Shine?

Sunshine is so important that the weather man keeps a daily record of the number of hours of it that we have. He has found that over the greater part of the United States not more than two-thirds of the daylight hours are sunny, though in the western highlands three-fourths of them are. But



Here are twelve pictures of the earth in its yearly march around the sun. You will notice that, no matter on which side of the sun the earth may be, its axis – or a line running through the earth from pole to pole— is always tilted in the same direction for anyone looking down at the solar system. Let us suppose you live in London, New York, or San Francisco. You would be living in the Northern Hemisphere—or that half of the globe that is north of the Equator. It is the half that the picture shows; for the Pole that we see in the picture is the North Pole. Now you will see, if you look closely, that during the winter months the North Pole is tipped away from the sun and is in shadow. The result is that the whole of the Northern Hemisphere, whirling around every day on its axis, is getting less sunlight than the Southern Hemisphere during those months, and so we are having our winter. But during the summer months the North Pole is tilted toward the sun, instead of away from it, and is in full sunlight. So the whole of the Northern Hemisphere is then getting more sunlight than the Southern Hemisphere, and London, New York, and San Francisco are having their summer. In spring and autumn the two hemispheres are sharing about alike—but while we in the north are having our autumn, the Southern Hemisphere is having its spring.

men can be well and strong on much less sunshine than this. In certain parts of Northern Scotland the sturdy inhabitants see the sun for only about two-ninths of the daylight hours, or for an average of only 2¾ hours a day.

Where the Sun Goes at Night

The sun does not smile on all parts of the earth equally, as it might if the world were a great flat plain spread out directly beneath it. Because the earth is round, certain parts of it receive the sun's rays squarely—they come from straight overhead—but elsewhere the curve of the earth brings the surface slantingly under the beams. And one-half of the planet is always turned away from the sun entirely—it is in darkness; though luckily the earth turns round, so that all sides get the light once in twenty-four hours.

When a Day Is Six Months Long

If you look at the diagram you will see that between the circles around the earth near the Equator the sun's rays strike the ground almost vertically; that is, they are about straight up and down. In this zone—or belt—the day and night are each about twelve hours long at all times of the year. The longest day and the longest night last only a little over thirteen hours.

But between this zone and the Poles the day varies greatly in length. It may last only a few minutes or it may be as much as six months long; and while one Pole is having six months of day, the other is having six months of night. The farther one goes toward the Poles, the longer are the days in summer and the nights in winter.

Why the Day Varies in Length

So Quito (kē'tō), Ecuador, has days and nights that vary only a few minutes from twelve hours all the year round, it is very near the Equator. At Key West, Florida, the longest day measures about fourteen hours. St. Paul, Minnesota, very much farther north, has a summer day that is sixteen hours long; London, nearly seventeen; Stockholm, Sweden, more than eighteen; and Nome, Alaska, about twenty-two. At the North Pole the day lasts six months.

All this will be easy to understand if you will try the following experiment. Take a small globe, or thrust a long pencil through the center of an orange. Then darken the room and hold the globe in front of a strong light, as the boy holds it in the picture—a flashlight will do. Tip the globe a little, so that the top, or North Pole, will point away from the flashlight just enough to keep the light from shining on it. You will notice that the South Pole, at the other end of the globe, is in the light. Now turn the globe slowly on its axis—or twirl the pencil. You will see that spinning the globe does not have anything to do with the amount of light that reaches the North Pole. It stays in darkness, just as the South Pole stays in light. In other words, the South Pole keeps having day and the North Pole keeps having night, though on the Equator day and night follow each other in any one spot as often as the globe is turned all the way round.

The Equator and that part of the globe which lies directly north or south of it always get more sunlight than the parts near the poles. Of course the tilt of the earth's axis sometimes brings one pole into the sunlight and sometimes the other, but it is nevertheless true that the middle part of the globe is in the sun all the time, and gets his rays much more directly than do the lands farther north and south. On this little map you can see by the shading how much sunlight any part of the globe gets in the course of a year. If you lived at the mouth of the Amazon you would get all there was to be had, for you would be at the Equator, where the sun's rays are more nearly direct than anywhere else in the world. But as you traveled north or south, you would find that they grew less and less violent.

But this does not explain why days should be of different lengths at different times of the year. If you should keep on turning the globe in the position it is now in, the North Pole would never see the light and the South Pole would be bathed in unending sunshine, while all the places between would have days and nights of fixed length all the year round. So let us see what happens to give us short days in winter and long ones in summer. Without changing the position of your globe, trace with a pencil, as you twirl the globe, the edge of the shadow all the way round it. You will find that the part of the globe south of the Equator is getting a good deal more light than the northern half. The southern half is having its summer, and the days there are longer than the nights.

But the earth does something more than spin. It also circles round the sun once a year. You may see what happens during this long journey if you will walk slowly around the light, always keeping the globe tilted at just the same angle that you held it at to start with and the North Pole pointing in the same direction. When you are a quarter of the way around the room, the South Pole begins to grow dark and the North Pole to grow light; and you will notice that the part of the globe north of the Equator now gets as much light as the southern part. It is now spring above the Equator and autumn below it, and the days and nights everywhere on the globe are of equal length.

We have a name that we give to this moment when the sun is directly over the Equator and the days and nights are of

equal length. We call it the equinox (ē'kwĭ-nŏks), from two Latin words meaning "night of equal length." There are two equinoxes in a year, the spring equinox on March 21st, and the autumn equinox on September 21st.

When you have circled half way round the light and are opposite your starting point, you will be in the same position as the boy in the second illustration. The North Pole of your globe now leans toward the sun and is constantly in the light. It is having its six months of day. But the South Pole is now in continual darkness. It is having its six-months-long night.

Now compare the line on the globe where the shadow ends with the line you drew when on the other side of the room. You will see that the two lines fall in quite different places. More light now strikes the upper part of the globe than the lower part. The days will be longer north of the Equator than south of it, and the northern part of the earth will be having its summer.

So you see it is the tipping of the axis of the earth toward or away from the sun that makes the days grow longer or shorter and causes the seasons. If the earth were not tilted in this way, we should have the same temperature all the year round and our days would never change in length. And the sun would always rise and set at just the same point on the horizon.

Here is the sun—impersonated by the boy with the flashlight—and the earth, which is revolving round and round the sun. In picture number 1 the North Pole is tipped away from the sun; the Northern Hemisphere is having its winter and the North Pole itself is having its six months of night. But in picture number 2 the earth has got around to the other side of the sun; so now the North Pole is no longer tipped away from the light. It is having its six months of day, and the Northern Hemisphere is having its summer. The dotted line in the second picture shows where the shadow fell when the North Pole was tipped away from the sun. But of course the earth does not really tip back and forth. It always stays in the same position with relation to the stars; its slant in relation to the sun is what changes—and gives us our seasons. Of course the earth is all the while spinning, even while it revolves around the sun. It is the spinning that gives us our day and night. For it takes twenty-four hours for our ball to turn around, and during that time any given spot has been turned toward the light part of the time and away from it part of the time—it has had its daylight and dark.

We who live to-day know that it is the change in the tilt of the earth toward the sun that causes the seasons. But in ancient times, before men knew that the earth travels round the sun, they naturally thought it was the sun that traveled back and forth in the sky. He seemed to them to start in the south in December and rise each day a little farther north and mount a little higher in the heavens. When the longest day of the year was reached, on June 21st, he had climbed to his highest point in the sky. People always celebrated the day. Then he turned and went south again—and we call the moment before he turns the solstice (sŏl'stĭs), from two Latin words meaning "the sun standing still."

The line on the earth which at this time has the sun directly overhead has been named from a Greek word that means "to turn"—we call it a

Photo by Keystone View Co.

Perhaps it will be your good fortune some day to see a total eclipse of the sun, and then you will learn, in a startling way, how much the sun has to do with the temperature. For though he is hidden but a few moments, as the moon swings across his face, a strange darkness and chill immediately settle over the earth.

"tropic" (trŏp'ĭk). There are two of them—one to mark the line farthest north that the sun reaches in its swing back and forth, the other to mark the southern end of its journey. When the northern half of the globe has its longest day—or summer solstice—the sun is directly overhead along the line on the earth that we call the Tropic of Cancer (kăn'sẽr); and when it has its shortest day—or winter solstice—the sun is directly above the Tropic of Capricorn (kăp'rĭ-kôrn), which is the line of turning south of the Equator. If the stars could be seen in the daytime and you were to sight past the sun on June 21st, our longest day, you would see a group of stars behind him that the ancients used to call the Crab—for "cancer" is the Latin for "crab." The star group was probably named for our little crusty friend who always walks backward, because the sun, on reaching just this point in the sky, seemed to back away and start south again. And the line on the earth which is directly under the sun at this time was named for the group of stars in which he seemed to turn around; it was called the Tropic—or turning point—of Cancer.

In the same way, if you were to sight past the sun on December 21st, our shortest day, you would see him against a group of stars that the ancients called the Goat—the Latin word was "capricornus." The group was probably so named because there was a myth that the young sun god had once been nursed by a goat. So the line on the earth which has the sun directly overhead when he turns north again was named for the group of stars in which he seems to face about—the Tropic of Capricorn.

That portion of the earth's surface lying between the two Tropics is called the Torrid Zone, or the Tropics. North and south of the Torrid Zone are the North Temperate and South Temperate zones, reaching to the Arctic and Antarctic circles. Inside those circles lie the Frigid zones.

It is the amount of sunlight we get that really governs our annual march of weather. The "swing" of the sun from north to south in the heavens gives us the snows of winter and the fruit and flowers of summer. It gives us our long summer twilights and the early sunsets of December. To the Tropics it brings the wet and dry seasons, to the Poles six months of day and night. It marshals the endless pageant of the seasons.

Reading Unit No. 3

SUMMER HEAT AND WINTER COLD

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the temperature on the tops of some mountains? 1-207

Why is it warmer close to the earth than high up? 1-207

Which of the sun's rays can we see? 1-208

When does winter begin in your latitude? 1-210

Where is the coldest place in the United States? 1-210

When does summer begin in your latitude? 1-210

What are the seasons at the Poles? 1-211

Things to Think About

Why does the sun beat more strongly on the Equator than on other points on the earth's surface?

Why does the air grow colder as we go higher up?

Why can human beings live in climates where plants die during the winter?

Why is cold weather good for us in some ways?

Picture Hunt

Why are the mountain tops in the background covered with snow? 1-207

Why is it hottest at the Equator? 1-208-9

Related Material

What was the mythological explanation of the seasons? 14-413-18

Why do the seasons change? 1-111, 201-3, 206-8

What are the plants of the Arctic regions? 2-195

What are the plants of the Temperate Zone? 2-196

How are plants fitted for extreme weather conditions? 2-203-7

How does the length of the day affect plant growth? 2-223

Leisure-time Activities

PROJECT NO. 1: Show the difference between the strength of sunlight at the Equator and in the Temperate Zone by using a globe and two flashlights, 1-208.

PROJECT NO. 2: Collect and mount photographs of activities in your neighborhood during different seasons.

Summary Statement

The high temperatures of the tropics are caused by the direct rays of the sun, whereas the temperate and polar regions receive the slanted and less intense rays of the sun.

Here are pictures of our old earth at every season of the year. We start with the North Pole tipped away from the sun. It will be winter in the north.

When the earth has traveled a quarter of the way around the sun, spring has come. Birds begin to sing and buds to burst. The farmer sows his seed, and every small boy's knuckles are grimy from playing marbles. And when the earth has gone halfway round, as shown in the lower left-hand corner, we are having summer.

By autumn the earth has covered three-fourths of its circuit, and is on the home stretch back to its starting point in midwinter. The lower right-hand corner shows you the point it has reached.

Photos by Swedish Railways, N. Y. State Dept. of Commerce, and Cornelia Clarke

Photo by Calif. Fruit Growers' Assoc.

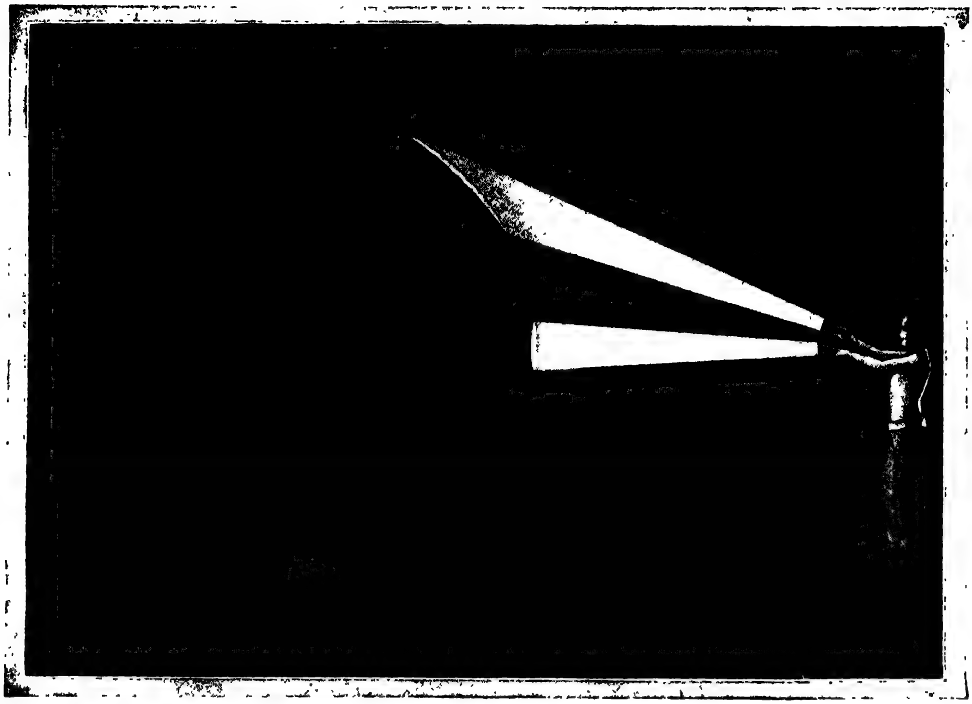
When you eat an orange on a snowy day in winter, do you ever stop to picture the beautiful sunny orchard where it blossomed and grew and ripened? Here is such a grove in California, with the oranges ready for gathering. And yet, in spite of its warmth, there are snows only a few miles away, on the mountains.

SUMMER HEAT *and* WINTER COLD

How the Heat and Cold Are Dealt Out over the Earth, and How We Manage to Measure Them

ALL the warmth on the surface of the earth comes from the sun, except a very little that filters out from the earth's hot interior. But strangely enough, this does not mean that the nearer we get to the sun, the hotter we are. On the contrary, as we go up into the air we get colder and colder. Only a mile above the earth the weather is freezing on the hottest summer day; and aviators who have flown some eight miles up find the cold unbearable. Even on the surface of the earth high mountains are topped with snow the whole year long.

Of course it all sounds like a contradiction. If the sun gives us our heat, why should we get colder and colder as we get nearer to him? Because as long as we stay close to the earth, we are tucked in with a soft blanket of air which, like a downy coverlet, holds the warmth in. The sun's hot rays warm the earth and also the air around it. But the air loses its heat faster than the earth does, because it is so much less solid. As it cools, however, it keeps receiving heat from the warmer earth, and so is kept at a more or less even temperature. Most of the heat in the air comes, then, not directly from the sun but from the earth. So the farther away we go from old Mother Earth, the colder we grow. High mountain tops are always snow-



You can see for yourself that the flashlights are the same size and give the same amount of light. But the rays from the one in our boy's left hand fall directly on the surface of the sphere and so light a much smaller area than those from the right-hand flashlight, whose rays fall slantingly and so spread over a large surface. That is exactly what happens to rays falling on the earth from the sun. Those reaching the part of the earth toward the poles are distributed over a great deal more surface than those that strike the Equator, so they cannot heat the earth nearly so much. That is why the climate is so hot at the Equator.

clad because the air there is too thin to hold the heat in.

The sun's heat comes to us in rays that are much like light rays, but with two great differences: our eyes can see the light rays but not the heat rays, while our bodies can feel the heat rays readily but the light rays almost not at all. Both heat and light travel at the same rate of speed and are distributed over the earth in the same way, according as the earth is tilted under the rays of the sun.

You see, the earth is wrapped in a great blanket of air some two hundred miles thick. Heat waves from the sun must pierce this envelope before they reach the ground; and of course as they travel through it, the air steals some of their warmth.

How the Air Steals the Heat

Now if you were to thrust a red-hot poker straight through a piece of ice, you would expect the poker to be a good deal colder when you pulled it out. It would have given off some of its heat to the ice--or, as we commonly put it, the ice would have cooled the poker. But suppose, instead of thrusting the poker straight through the ice, you put it through slantwise. It will have to pass through a good deal more ice than when it went straight through. So naturally it will be cooled still more.

Why It Is So Hot at the Equator

This is exactly what happens to a sunbeam passing through the air to reach the earth. When it falls from straight overhead, the two hundred miles of air cool it to a certain extent, but nowhere near so much as when the ray has to travel slantingly to the earth. So at the Equator the direct rays of the sun at midday are always hot, but as one goes toward the Poles they are always more and

more slanting, even at noon, and carry less and less heat.

Then, too, a given square mile of the earth is bathed by a greater number of the sun's rays when they strike it from straight overhead than when they fall on it slantingly. This is because a slanting ray has to cover a good deal more ground than a ray that falls straight; so its heat is distributed over a larger surface. You will remember that the same thing is true of the light rays.

It is not that anything has happened to the flashlight in the right-hand picture. It is only that its rays fall slantingly on the fence and so are spread over a big oval patch, instead of striking directly and being concentrated on a small surface. The same thing happens when you do not direct the rays of a burning glass directly on a paper; they are too weak to start a fire. And that is just what happens on our globe. Near the Equator the sun's rays strike almost directly, and so seem very hot. But on account of the curve of the earth, they strike slantingly on most of North America; and the farther north you go, the weaker they seem. You can see on this map how little sunlight Alaska gets in comparison with Northern Brazil.

You will have no trouble proving all this with a burning glass. A common reading glass will do. Throw the sun's rays directly on a sheet of white paper. Try to make the circle of light as small and as clear as you can. It will not take long to set the paper on fire, for you are directing the sunbeams straight at the paper.

Why the Arctic Regions Are Cold

Now turn the paper at an angle, so that the ray from the glass falls slantingly on it. You will see that the circle of light is spread out over a great deal more paper and that it takes much longer to start a flame. This is exactly what happens to sunbeams on the earth. Over a square mile on the Equator, where they fall from straight overhead, their heat is great. But let them strike somewhere in Canada, say at Ottawa, and the same amount of heat that a square mile got on the Equator has to warm nearly one and one-half square miles of Canadian soil. Naturally, it cannot accomplish so much.

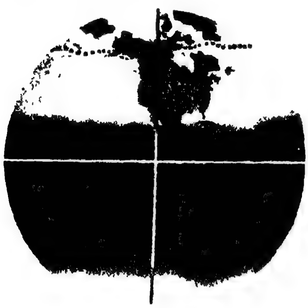
The same thing happens when a given part of the earth—let us say the northern half of the globe—is tilted away from the sun. The rays that fall over a square mile in summer are now spread over a good deal more than a square mile. Naturally they do not heat the earth anywhere near so much.

All this is what gives us our exciting variety of seasons, without which life would seem so much more monotonous. Whenever the people north of the Equator are tilted toward the sun, and so get his rays from high up in the heavens during more than twelve hours of the day, they are having spring or summer. And whenever they are tilted away from him and so see him low in the sky for only a few hours a day, they are having autumn or winter.

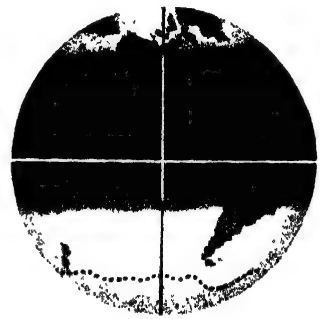
As the nights grow longer and the days shorter, earth and air lose more heat than they get from the sun. So the air grows

sharper and sharper and the ground freezes solid. On December 21st, winter begins. Streams and ponds put on a stout overcoat of ice and all green things go sound asleep. Then we may prepare for many a sharp nip, especially if a cold wave comes riding in on a blast from Northwestern Canada, where most of our cold waves seem to come from. The thermometer falls rapidly toward zero in the northern part of the United States and sometimes goes far below. Even Texas and Florida may be nipped by frosts.

The coldest places in the country are in North Dakota and Montana. At Devils Lake, North Dakota, the average temperature for January is less than 1° above zero; and at Poplar River, Montana, the temperature may go as low as 67° below zero. But in Northern Siberia is a little village that would seem to hold the record—at Verkhoyansk it can get as cold as 90.4° below zero.



As the earth travels around the sun it is sometimes tilted one way and sometimes another with relation to the sun. That means that sometimes one part of the earth and sometimes another is getting the full force of the sun's rays. The picture at the left shows, in the shaded band, what is the hottest part of the earth when the North Pole is tilted away from the sun. The "heat belt" then lies well to the south. But as the earth swings round the sun, the Northern Hemisphere comes in for its share of sunlight. Then the heat belt moves toward the north, as shown at the right.



Why We Are Well When It's Cold

Although nearly every cold wave brings the news of people frozen to death, the biting wind really carries health and energy to most of us. It whisks away dust and smoke, blows the stale air out of all the corners, and sweeps everything clean.

As a matter of fact the cold lasts for a long time after the sun has faced about at the winter solstice and is climbing up the sky again. It is hard to realize that on February 20th he is sending us just as much heat as on the 20th of October. The difference in the temperature of the air on those two days is due to the fact that when the earth has once cooled off it takes a long time to heat it up again; and when it is thoroughly hot—as it is, say, in August—it takes a long time for it to cool off.

But as the sun mounts higher and higher in the sky and smiles on the earth longer and longer every day, his rays finally conquer Jack Frost. On the 21st of March spring comes in and days begin to get longer than nights. Now the sun gives the chilly earth more heat than the nights can steal away. Streams are breathing again, the snow has slunk out of sight, and grass and flowers and trees awake. At last, on June 21st, summer comes in to stay as long as the sun is high enough to keep the earth from cooling off

When he begins to lose the contest on the 21st of September, autumn begins. Sometimes there is a short warm spell that we know as Indian summer, so named, some people say, from the fact that the Indians, who cared more for the hunt than for the drudgery of farming, left their crops to be gathered during those few last warm days. But autumn nights are always sharp; and trees and flowers, done with their labors for the year, drop their seeds and fruits and settle down again for their long nap. And in shedding leaves and pods they give back to the soil part of the materials they have taken from it as nourishment during the growing season. So you see our good Mother Earth never gets old and outworn.

When a Day and a Night Make a Year

You will remember we said that climates grow colder as one travels toward the Poles. Let us see if the thermometer bears us out. At Key West, Florida, the average summer

Photo by American Tel. & Tel.

This is what our grandparents would probably call "an old-fashioned winter," perhaps with the comment that winters no longer are what they used to be. There are even people who are convinced that the Gulf Stream is changing its course, and that by swinging inshore it will give New York a climate much like that of Palm Beach. But none of these speculations must be taken seriously. The weather man says that winters are just what they always have been--and he knows. Our grandparents forget the warm winters and remember the cold ones. And a few mild seasons do not prove that there never can be cold ones again.

temperature is 81° F., at New Orleans 80° F., at St. Louis 77° F., at St. Paul 70° F., and at Winnipeg only 66° F. At the Poles there are only two seasons, a warm one and a cold one. The warm one is a day six months long, and the cold one a night of the same length. Of course the warm season is nothing that we should call summer; for near the Poles the ice never melts at all. The few people who defy King Winter and live all the year round amid ice and snow have little to eat besides the food they get from the sea—fish and blubber, or fat, from various sea animals.

When Is the Growing Season?

The differences of climate have a very important effect upon human life. For the growth of crops depends on the temperature of the air and of the soil, and the welfare of the people depends upon the growth of crops. The "growing season" is the time between the last frost in spring and the first one in autumn. On its length and warmth depend the kind of crops that are raised. Few crops can thrive when the temperature stays below 60° F. for long at a time. In parts of Florida and California the growing season lasts all the year round, but over the greater part of the United States it covers about two hundred days. In Southern Canada it is long enough for a bounteous crop of wheat but not long enough for corn.

Fortunately human beings are more hardy than plants. With proper protection they can withstand the burning heat of the desert or the bitterest arctic cold. That is one reason why man has been able to conquer the earth.

Reading Unit No. 4

A YARDSTICK FOR THE WEATHER

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How is temperature measured? 1 213

Who invented the first thermometer? 1–213

What happens to things when they are heated? 1 213

At what temperature does alcohol freeze? 1 213

What are the different types of thermometers? 1 214

Does "o" degrees mean the same on all thermometers? 1 214

What are the freezing and boiling points of water? 1 214

Things to Think About

Why is alcohol used in low-temperature thermometers?

How may electricity be used to measure temperature?

How is a centigrade scale determined?

Picture Hunt

How are the freezing and boiling points on a thermometer established? 1 214

How do the scale readings on a Fahrenheit thermometer compare with those on centigrade thermometers? 1 214

Related Material

What is the effect on plants of temperature changes? 2 194, 217, 222

What is the temperature of the ocean depths? 1 66

How is temperature affected by clouds? 1 237

What is the temperature of the human body? 1–393, 2–348

How do temperature changes cause winds? 1 227

What is a metallic thermometer? 1 391

How does the Weather Bureau record temperatures? 1 274-76

How is indoor temperature regulated? 1 477, 480

Practical Applications

How are very low temperatures measured? 1-213-14

How are very high temperatures measured? 1 213-14

Leisure-time Activities

PROJECT NO. 1: Make a Galileo thermometer, 1 213.

PROJECT NO. 2: Check the boiling and freezing points on a thermometer, 1-214.

Summary Statement

Thermometers measure temperature, making use of the fact that certain substances expand when heated and contract when cooled.

When Nature dresses the world like this, we know that the weather must be cold. But just how cold, no icicle or snowdrift can tell us. And even a chilblain or a frosted nose makes a poor thermometer.

A YARDSTICK *for the* WEATHER

It Settles All Our Arguments about the Temperature and Tells Us Just How Hot or Cold We Ought to Feel

IN OLDEN times men had no sure way of telling how hot or cold a day was. There must have been endless disputes on the subject when one person thought the heat was pretty bad and another felt quite comfortable. To-day we do not have to rely on our feelings. An impartial little instrument—the thermometer, of course—tells us just how warm or cold we have a right to feel. It is hardly in human nature not to take satisfaction in being able to say, on some hot July afternoon, "It was ninety in the shade on my back porch just now!" And somehow we like to read in the paper that the temperature has been the lowest in forty years. It is silly, perhaps, but people are like that. The worse the weather is, the more they like to boast about it. So they watch the thermometer from day to day and are happy if they find that it was colder around their house than anywhere else in town.

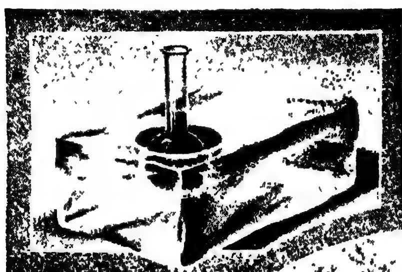
The first thermometer was made more than three hundred years ago by the famous Italian scientist, Galileo (găl'ĭ-lē'ō). He had found out that nearly all substances, whether gases, liquids, or solids, fill more space when they are heated. That is, they expand. He noticed, too, that when he heated liquid in a glass, both the glass and the liquid expanded, but the liquid more than the glass. So he made a thermometer by using a closed glass tube filled partly with air and partly with liquid. Later he filled it with alcohol colored red, the advantage of alcohol being that it will not freeze till it goes down to 162° below zero Fahrenheit. Of course a thermometer that freezes easily is useless in very cold weather.

Nowadays alcohol is used in all thermometers meant to register very low temperatures, and mercury (mûr'kû-rĭ), or quicksilver—a heavy, silvery fluid—in most of the others. For very high temperatures thermometers are filled with gas.

For scientific experiments at high temperatures electrical thermometers are also used. There are two kinds. One makes

use of the fact that when two different kinds of metal are joined together, an electrical current will be set up if the temperature is changed at the point where they meet. The second kind relies on the fact that certain metals offer a great deal more resistance to an electrical current if they are heated.

In all thermometers a scale for reading changes in temperature is marked alongside the glass tube on a strip of metal, wood, or china.



Our common thermometers are made in different ways, but the principle on which they are made is very simple. First a long tube with a bulb on the end is partly filled with a liquid, such as mercury. Of course the bulb is much smaller than the one the boy holds in his hand, and the tube is much longer. The end of the tube is then closed. Next, two points are marked off on the wooden or metal scale to which the tube is attached. One of these is the point the top of the liquid will reach at a temperature of 212° Fahrenheit, or the boiling point of pure water at sea level. That temperature is easy to find, for as soon as water begins to boil it has reached 212°. The other point to be marked on the scale is the level of the top of the liquid at the freezing point of pure water at sea level, or 32° Fahrenheit. It is the temperature at which a cake of ice begins to melt. Once these two points have been found, it is simple enough to divide the distance between them into the proper number of degrees.

The thermometer on the left has the centigrade scale; the one on the right, the Fahrenheit. You will notice that on the centigrade thermometer, the freezing point is marked zero and the boiling point 100—and the distance between the two is marked off into a hundred degrees. But on the Fahrenheit thermometer the freezing point is marked 32 and the boiling point 212; and the distance between them is marked off into 180 degrees. But the actual temperature of the freezing or boiling point is of course always the same, no matter what you may call it.

What Is Zero?

There are different kinds of scales for reading temperature. Scientists and the people of most European countries use what is called the centigrade (sĕn′tĭ-grād) thermometer. On it the space between the freezing point and the boiling point is divided into a hundred parts—or degrees. Indeed, it is from that fact that the thermometer takes its name—for "centum" is the Latin for "hundred" and "gradus" the Latin for "degree." The freezing point on a centigrade thermometer is marked zero and the boiling point 100. The temperature halfway between the two would be at 50 on the scale, and would be written "50° Centigrade."

Another scale, first laid out in 1720 by a German scientist named Gabriel Fahrenheit (fä′rĕn-hīt), has for its zero the temperature of a mixture of equal parts of snow and salt. For the other end of his scale Fahrenheit took the temperature of the human body; and he divided the space between into ninety-six degrees. As it works out on our present Fahrenheit thermometer, the freezing point is at 32° and the boiling point at 212°—with 180° between the two, instead of 100°, as on a centigrade thermometer. This is the scale in common use in most English-speaking countries.

Reading Unit No. 5

AN OCEAN OF AIR

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the source of the weather? 1-217

How far up from the earth's surface does the air extend? 1-217-18

What is the temperature of the air three miles above the earth? 1-218

Where does the stratosphere begin? 1-218

Why is the stratosphere a place with no weather? 1-218

What is meant by a vacuum? 1-218

What is the stuff we call air? 1-210

How do rivers and streams get their supply of water? 1-219

Things to Think About

How do plants maintain our air supply?

What causes a sunset?

How is the earth's water supply maintained?

How do balloons help us to study the upper atmosphere?

Related Material

What is the work of the United States Weather Bureau? 1-275-78

What were weather conditions like in prehistoric times? 1-196

How is air used in an automobile? 10 283-84

Does air conduct electricity? 1-514

How does the purity of air affect plants? 2-50

How does air affect the transmission of light? 1-424-26, 427, 431

How does air resistance cause an airplane to rise? 10-315

How fast does sound travel through air? 1-445-46

Practical Applications

How is the stratosphere explored? 1-216-18

How can explorers overcome the lack of oxygen at high altitudes? 1-218-19

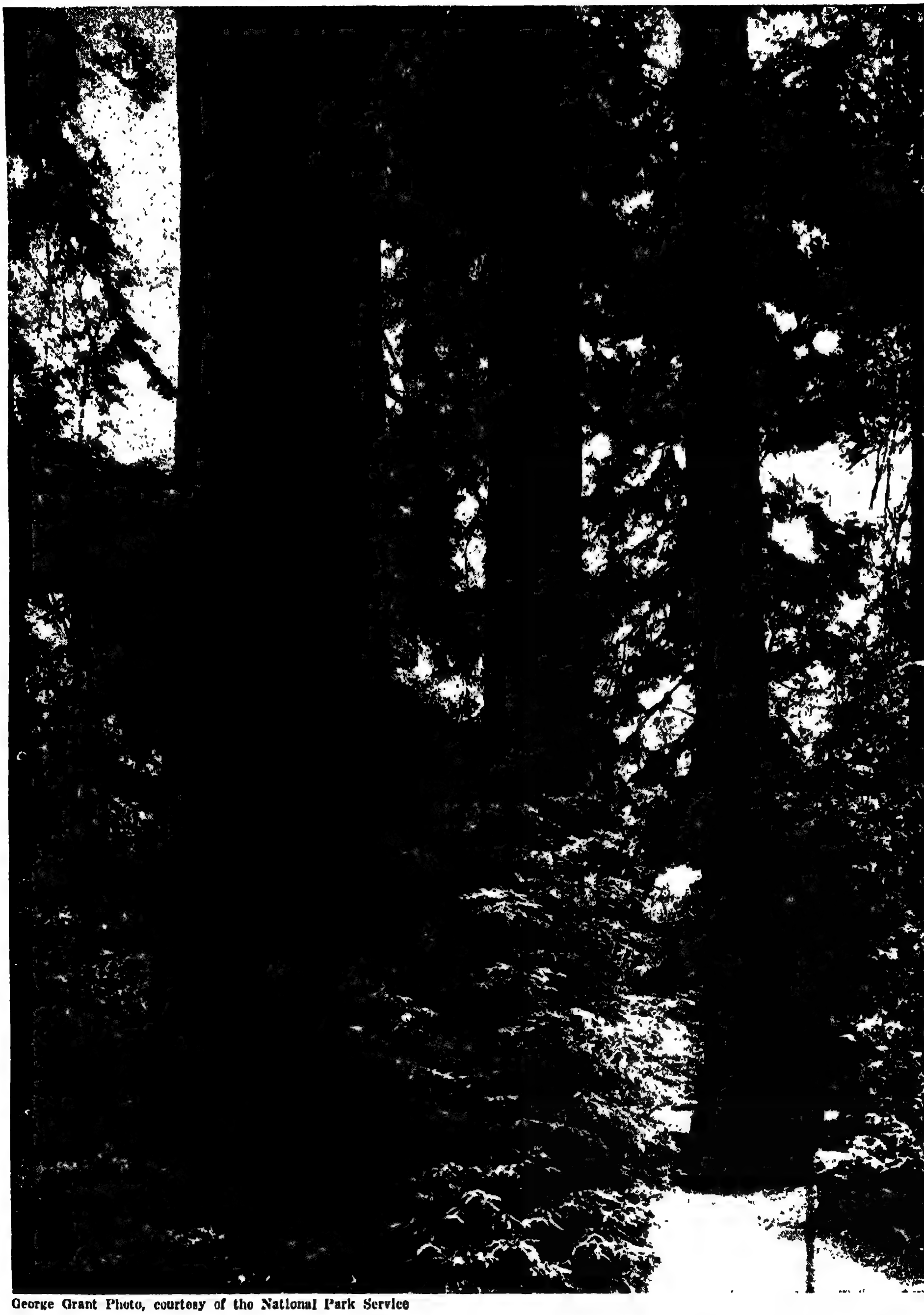
Leisure-time Activities

PROJECT NO. 1: Learn how to show the presence of moisture in the air, 1-219.

PROJECT NO. 2: Learn how to see the dust in the air, 1-219-20.

Summary Statement

The blanket of air around the earth is composed of oxygen, nitrogen, water vapor, carbon dioxide, rare gases, and dust.



George Grant Photo, courtesy of the National Park Service

It is hard to believe that these giant California redwoods depend more on sun, air, and water to build their huge bulk than they do on the nutrients they draw from the soil. But that is the fact. With the help of light, plants can combine water with carbon dioxide from the air and so make stems and leaves.

Photo by American Museum of Natural History

All of the feathery blanket that has tucked in this little Canadian cabin and loaded the shrubs and trees fell down out of the air. But before it began to descend, there was not a flake of it to be seen—there was only a cloudy sky overhead. Where, then, did all those tons of white stuff come from?

An OCEAN *of* AIR

Floating in a Thin Substance That We Cannot See, We Get All Our Weather from It

ONE of the most amazing things in the world is air. It is all around us. We breathe it, we walk in it, we fly in it; it is spread all through our bodies—in all their tiny crevices—and the weight of thousands of pounds of it bears down upon us every instant of our lives. And yet we can neither see it nor smell it nor feel its weight! If it were not for certain things it does we should not know that it was there at all. We see the tossing trees and feel an invisible something that buffets us about, and we say it is the wind. But wind itself is as hard to see as fairies are.

It is out of this magical blanket, resting on us so softly, that all our weather comes. Under the tireless action of the sun all the amazing varieties of hot and cold and moist and dry, of breeze and calm and tempest, are combined. The air and its moisture are like the steam in a mighty engine which manufactures weather in twenty-four-hour shifts, and the sun is the furnace that heats the steam. But so many are the various forces in the engine that the weather of no two years is ever exactly alike. Most of our weather is made in the troposphere (trō′pō-sfēr), the stormy layer of air just above the shallow one in which life exists. We do not know just how high up the air reaches; probably from two to four hundred miles, though traces of it may extend out two thou-

sand miles in space. Of course there is no definite limit; the air just fades away to nothing. As soon as we start upward, it gets colder and thinner. If we were starting for a winter trip to the moon, we should find that when we got up about three miles the air would be down to zero Fahrenheit, and a good deal thinner than on the earth;

Here is a recipe for making a shower. Take one good strong sun and place it over an ocean. At once its heat will set to work turning the water into vapor—or, as we say, evaporating it. The rising vapor is shown by the white column in the left-hand picture. Now take a good-sized column of smoke and blow it over the sea into your water vapor. Be sure to do this at a high enough elevation for your rising vapor to be somewhat cooled. Now you can watch your water vapor condense in tiny droplets around the little solid particles in the cloud of smoke. You will have an active rain cloud, which will soon begin to drop its moisture as it drifts in over the land. Of course showers are made under many differing circumstances, but it is always the same principle at work.

and at six or seven miles it would be so thin that we could not live in it unless we took along a supply of oxygen. Seven or eight miles up the temperature would be around seventy-five degrees below zero Fahrenheit, for it drops about fifteen degrees for every mile we rise.

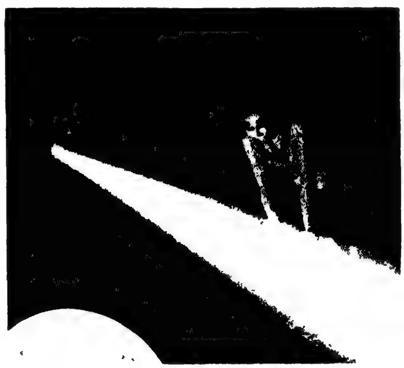
Secrets Brought Down in Balloons

But here there would come a change! We should find ourselves in the second of the great layers of atmosphere. It is called the stratosphere (strā'tō-sfēr). We know very little about it, for men have never ascended more than 13.7 miles. But V-2 rockets carrying instruments have gone far above the earth—as high as seventy-five miles—and on coming down again have told some very interesting tales. Among other things they have reported that the temperature there stays at about seventy-five degrees below zero all through the stratosphere, and that the air some twenty-five miles above the ground is probably only about one three-thousandth as dense as at sea level. Here are no storms—no "weather" in our sense of the term, though there is a shallow layer of very moist air. The winds blow so gently as not to count.

Of the still higher levels the rockets report amazing things. The air is so thin as almost not to exist. Yet we know that air is there, for meteors take fire from rubbing through it on their swift flight to earth. And thin as it is, there is enough of it to carry heavy charges of electricity, for the "northern lights," which are really an electrical display, mount high into these distant levels. Thirty miles up the rockets enter a zone of terrific heat, where for ten miles the temperature reaches 170°. Then comes another cold zone, where, at levels between the forty and fifty mile marks, the temperature probably goes as low as 150° below zero. On top of this layer is another zone of great heat—as high as 638°. It extends up at least seventy-five miles.

The air is a mixture of certain substances that we call gases, and gases are the lightest and thinnest forms of matter. If you should separate any hundred cubic feet of air into its various parts, you would get seventy-eight cubic feet of a gas called nitrogen (nī′trô-jĕn) and twenty-one of oxygen (ŏk′sĭ-jĕn). The one cubic foot that would be left would be made up of what are called the argon gases and certain other substances—water vapor, carbon dioxide (dī-ŏk′sīd), dust, and ozone. Although these last are so small a part of the air, neither plants nor animals could live without them.

If you find it hard to believe that the air contains moisture—tiny particles of water that we call water vapor—watch a pitcher of ice water that has been brought into the room on a hot day, when the air seems quite dry with the heat. In less time than it takes to tell, the pitcher will be covered with fine beads of water. These have not come from inside the pitcher, for none of the water can possibly leak through it. They have all come out of the air.



If you find it hard to believe that the air is full of dust, just darken the room and look at the ray of light coming in through the keyhole. It will be full of tiny dancing particles. Now moisture, when it condenses, always forms into tiny drops around one or more of these little particles or on some other solid substance. In our picture it is condensing into droplets on a pitcher of water and so the pitcher seems to sweat. But none of the water came from inside the pitcher; it was all in the air.

The water vapor in the air cannot be seen, but normal outdoor air is almost never without it. It is drawn up from the sea, from lakes and rivers and brooks, from the washing on the line, and from the breath of men. Wherever moisture is found, it is being taken up into the air. If you hang up a damp cloth it will soon get dry; the water in it has turned into vapor, or "evaporated."

But sometime the water will all come back to earth again, in the form of rain or hail or snow or dew. For every drop of moisture that the earth gives to the air it always gets back again. The air merely serves to scatter the water over the surface of the earth. If it did not do so, nothing but the ocean would be wet, and every inch of land in the world would be desert. It is only the air that can draw up the water out of the ocean and sprinkle it over the land—thus making the streams and rivers that carry it down to the sea again.

Carbon dioxide is even more mysterious than water vapor. It forms only three ten-thousandths of the air, and yet without that tiny fraction of it none of the plants could live. It is what they breathe. And if all the plants should die, what would become of man and all the other animals? Carbon dioxide comes from fires and from the breath of animals; yet all the fires and all the animals in the world do not seem greatly to increase its quantity. For the plants are always at work. If it were not for them, we should die of the poisons in our own breath.

Ozone is still more mysterious. Not a great deal is known about it, except that it is a very powerful and active form of oxygen. There is only a very little of it in the air, though sometimes a sharp thunderstorm will set free enough for one to be able to smell it. Some people say it reminds them of a faint smell of horse-radish; others think it is more like ammonia or burning sulphur.

There is still one other thing that helps to make the atmosphere—the humble and ever-present dust. Surely this is the last thing that one would ever take to be beautiful or useful. But there is a great deal of

dust in the air besides the kind that has to be cleaned off tables and chairs—there is a soft, floating dust so fine that we cannot see it. And if it were not for this unseen powder we should never have rain or bright sunsets. For the gorgeous colors of the sunset are made by the rays of the sun as they tint the particles floating in the air; and as for the rain, we are going to find out a little later that every drop of it forms on a tiny core of floating dust. Even our skies would be less blue without the dust. For the tiny particles in the air—dust and moisture and atoms of gas—are what keep us from seeing the sky as it really is—a vault of inky black with stars and sun scattered over it! That is what the sky looks like on the moon, where there is no atmosphere; but on the earth the air spreads all of the rays of light that are constantly passing through it and sorts out the blue ones up in the sky. This is what gives us the azure dome of a summer's day and the soft, deep blue of midnight.

Dust is always in the air, even in the high, thin air above the clouds. If you let a tiny ray of sunlight into a dark room, you can see its shining path like a thin streak of gray light. What you are really seeing is the reflection of the sunlight on millions and millions of tiny bits of dust always floating in the air--little particles of ash and unburned fuel that have risen in the form of smoke. They come from millions of chimneys and from forest and prairie fires. Wherever anything burns, it must give off fine particles of dust in smoke. It is dust in the air that makes those long, slanting rays that sometimes lead, like shining paths, from the earth up to the sunset. People used to say that the sun was "drawing water." We know now that the sunbeams, piercing through a rift in the clouds, are reflected by all the tiny particles in the air, just as when they find their way into a dark room through a narrow slit in the blind.

But long before there were chimneys, long before man had a fire, there were gentle summer rains and beautiful sunsets. Where did dust come from then? It came from fuming volcanoes and from burning meteors, those bits of metal and rock that, plunging through the sky, get caught in our atmosphere and are burned by the heat they make in rushing through it. Even now more dust may be shot into the air by volcanoes than from all the chimneys and fires in the world. For a volcano often sends a cloud of dust as high as twenty miles, where it hangs sometimes for months and may be slowly wafted all the way round the world. Sometimes the dust is so thick and is spread so widely that it changes for a time the whole climate of the lands from which it shuts off the warmth of the sun. They turn cold even in summer. In 1816, after great volcanic eruptions in other parts of the world, snow fell and the temperature went below freezing every month of the year in Vermont.

Of all the substances in the air, water vapor and dust have the most to do with the weather. But before we can find out why this is so, we must make the acquaintance of those rude but jolly weather carriers --the winds

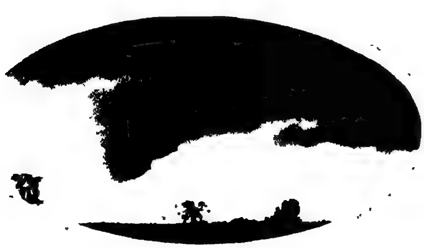


Photo by H. E. Zimmerman

Strange things take place in the air, such as the formation of whirling funnels like this one.

Reading Unit No. 6

WHAT MAKES THE WIND BLOW

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the wind? 1-222
What makes the wind blow? 1-222
What is meant by an "updraft"? 1-222-23
In what directions do winds blow from the Equator? 1-223
What does the spinning earth do to winds? 1-225
What are the trade winds? 1-225
Why is Spain warmer than New York? 1-225
What is meant by the "horse latitudes"? 1-225

Things to Think About

How may heat produce "updrafts"?
Why do winds tend to blow away from the Equator?
How do the trade winds affect weather?
Why do we find areas of calm air along the Tropic of Cancer and the Tropic of Capricorn?

Related Material

How are seeds and fruits carried by the wind? 2-210-12
How is pollen distributed by the wind? 2-111, 113, 145
How can energy be obtained from the wind? 1-352
How did ocean commerce flourish before the days of steamships? 10-150-64
How do the winds help cause hay fever? 1-376
How did the discoverers of the New World make use of the wind? 5-377, 476, 7-113-17, 10-158, 13-460-61, 462-63, 5?4
How do winds affect life, property, and transportation? 1-229-30

Practical Applications

How does the wind help transportation? 10-140, 159-73, 12-130
How is the wind used to help forecast the weather? 1-267
How has the wind been used to produce electricity? 1-508

Leisure-time Activities

PROJECT NO. 1: Make a weather vane, 14-48.

PROJECT NO. 2: Make and fly a kite, 14-499-502.

Summary Statement

Winds are started when large bodies of air, heated by the sun, rise and allow colder air to flow in to take their place.

WHAT MAKES *the* WIND BLOW?

How the Great Currents in the Air Have Helped to Make Our Climate and Our History

WHAT is the wind? Of course we know well enough how it behaves. We have seen all kinds of winds, from a little breeze barely strong enough to flutter a thistledown to blasts that snatch away our hats and send us chasing half a block to get them back. There are even tornadoes strong enough to pick up a house. But this boisterous, powerful fellow no one has ever seen, for he is made of nothing but air. He is the roving atmosphere. Winds are rivers of air that flow along over the earth at varying rates of speed. And they are very important. They bring us nearly all our changes of weather. Spring rains, summer storms, and winter blizzards are all brought by the winds.

And what is it makes the winds?

The answer is quite surprising. It is the sun that makes the winds.

Perhaps the easiest way to understand it is to watch the smoke from a lighted match. The smoke rises steadily upward, curving this way and that but always mounting. It cannot do anything else, for the flame has heated the air, and air that is heated expands or spreads out. This makes it lighter, because it is thinner than it was before it was heated. Now a bit of lighter air with heavier air all around it is forced to rise. The heavier air squeezes it up by flowing under it from every side. Warm air can no more keep from rising if there is cooler air around it than a cork can keep from coming up to the top of a pail of water.

The poet who lived on shore could sing, "Whichever way the wind doth blow, my heart is glad to have it so." But in the brave days when the buccaneers swept the Atlantic for jewels and gold, a heavy gale often left nothing but floating spars behind it.

Such upward currents of air as we see when a match is burned and the warm air carries the smoke up are known as "updrafts." Most of the movements of the air in the great outdoors are caused in

It may have seemed to you at times that whenever there was anything strange about the climate of a country, it was always safe to say that the Gulf Stream was responsible. Now the Gulf Stream cannot account for everything, but it does bring about some remarkable conditions. Above is a map with the arrows showing the course of the Gulf Stream through the Atlantic Ocean. At the right is a similar map showing the course of its twin, the Japan Current, which drifts down our western coast. Both currents begin in the warm waters near the Equator and end in the cold waters of the north.

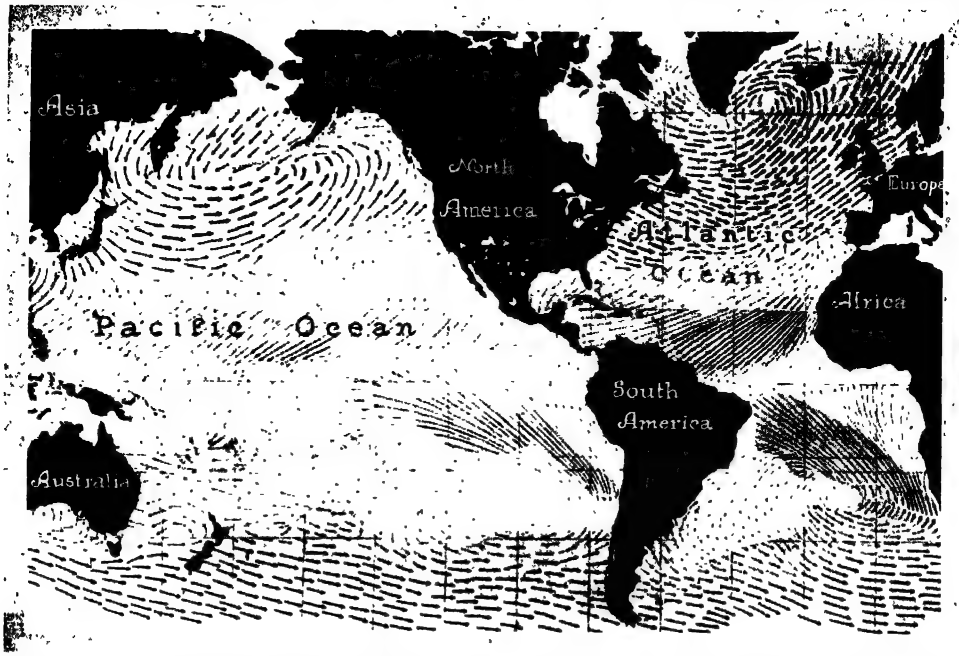
just this way—by the rising of air that has been warmed by the sun and the flowing of cold air into the place where the warm air has been.

Where the Wind Begins

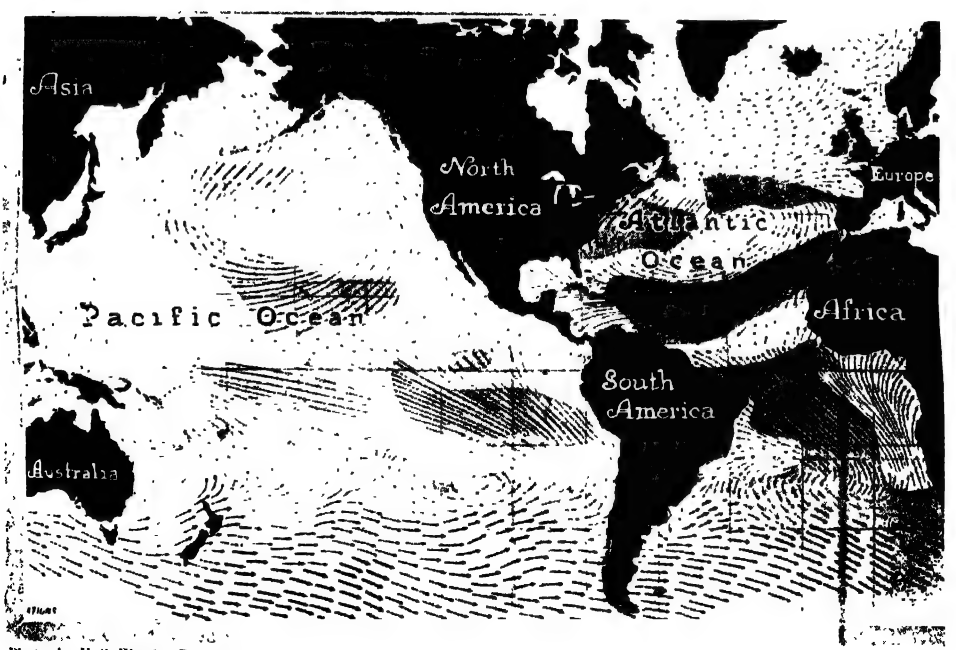
Have you ever watched water boil in a large pan? Wherever the flame touched the bottom of the pan, the water bubbled up fast; but if there were places around the edge where the flame did not reach the water there was fairly quiet. Now this is very much what happens to the air under the rays of the sun. All along the Equator, where the sun, is straight overhead, the ground is highly heated, and in turn heats the air over it. But farther north and south on either side, the sun's rays strike with less power and the air is a good deal cooler. So the hotter air along the Equator constantly "boils" upward, forced up by the cooler, heavier air that is crowding it from north and south. This cooler air, in its turn, is warmed by the burning sun, and is forced up by still more cool air; and so a current is kept constantly flowing from the cooler Temperate Zones toward the Equator. The heated air that boils up flows away to north and south and finally sinks to earth again, when it has been thoroughly chilled. Then it once more begins its journey toward the Equator, joining the procession of winds that are steadily marching there, drawn by the constant rising of the air where the sun is hottest. So it is the rising of overheated air that makes the wind start blowing.

But strangely enough, those winds that flow in from north and south, to rise in a fountain over the Equator, really flow from northeast above the Equator and southeast below it. If you were given time you might very well guess why this is. But we shall save you the effort. Their path is swerved to one side by the whirling of the earth.

It is true that the earth as it turns carries its atmosphere around with it—as much a part of it as the Rocky Mountains are. But it is also true that around the middle of the globe any given spot on the surface has to travel a good deal faster than a spot that is nearer the Poles; it has farther to go on its way around the earth's axis. Now



These are the winds that trample the oceans of the world in January. Their direction is shown by the arrows.



Photos by U. S. Weather Bureau

In July the sun is hottest north of the Equator. So the whole pattern of the winds has been shifted north.

the winds that seek the Equator start from regions where they do not have to turn very fast to keep up with the earth. Consequently, as they move northward and southward they are passing into new regions where the ground is wheeling faster and faster beneath them. The result you may clearly see for yourself. They have no way of picking up enough speed to keep pace with the more rapid turn of the earth's surface, so the land has to rush by while they maintain their steady march toward the Equator. The result is that their path on the earth is swerved from straight north and south toward the west, for the earth is spinning eastward under them.

What Are the Trade Winds?

Those winds blow steadily all the year round at an average of about twelve miles an hour; of old, in the days of sailing vessels, they used to be of great use to shipping. Because they kept such a steady course, they were called "trade winds"—for the old meaning of "trade" was "a straight path." They could always be relied upon to bring a ship to port. But they are of great importance even to-day, for the climate of the world depends mainly upon them to distribute the heat and cold.

Along the line where they meet at the Equator and rise in a kind of fountain, there is a broad belt of calm, where there are no steady breezes and the rain falls in torrents. Almost no single day is without its shower. This zone is known as the "doldrums," and used to be a terror to sailing vessels, which might be caught there for weeks on end and remain "as idle as a painted ship upon a painted ocean." Though steam has freed our ships from such inconveniences, we still have the phrase "in the doldrums," meaning "in the dumps."

On either side of the trade winds there is a broad belt of winds which blow across the Temperate Zones from west to east. They are called the "prevailing westerlies," and in the southern half of the globe, where their path lies mostly across the ocean, they blow so steadily and swiftly that sailors in the olden days called them "the roaring forties," since they swept along parallels of latitude in the forties. A vessel coming back from the East Indies found it easier to round Cape Horn than to sail into the teeth of such a gale.

The winds that sweep from west to east in the North Temperate Zone are more or less broken up by the unevenness of the land they cover, and so are a good deal more variable. Yet in the United States the breezes are commonly from the west, southwest, or northwest. And it is those businesslike winds which, blowing steadily off the Atlantic and the warm Gulf Stream which crosses it there, give England and Western Europe their mild, moist climate. For though Great Britain is as far north as Labrador, snow rarely stays on the ground there more than a few days at a time and skating is quite uncommon. And though the northern coast of Spain is actually farther north than New York City, it has so mild a climate that roses bloom there at Christmas.

The Horse Latitudes

Between the trade winds and the great belt of wind in each of the Temperate Zones there are calm spaces, with little or no breeze and clear skies. It is here that the air which is always boiling up at the Equator settles to earth again. In the northern half of the globe this belt is called "the calms of Cancer," named for the Tropic along which it lies; and in the south it is called "the calms of Capricorn," after the Tropic of Capricorn. But the sturdy sailors did not bother with such learned names. They called those calms "the horse latitudes"! For years ago when a sailing vessel carrying a cargo of horses was caught in the calms of Cancer on its way down to the West Indies, the horses often had to be thrown overboard when water began to run short. The old tars never lost a chance to coin a vivid phrase.

Of course, as the sun swings north and south in its yearly path, it carries the great updraft along the Equator with it. So at different times of the year, the doldrums are to be found at different places on the earth's surface, and the trade winds as well. They shift back and forth with the sun.

Reading Unit No. 7

BLOW, WINDS, BLOW!

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is always happening to the direction of the wind? 1–227

How do the winds tend to blow in the North Temperate Zone? 1–227

What causes all the earth's winds? 1 227

When is a movement of the wind called a cyclone? 1–228

When is a movement of the wind called a tornado? 1–228

What is meant by a "desert simoon"? 1 228

What are typhoons and hurricanes? 1–230-31

Things to Think About

How do cyclones form?

How does the air at the seashore move at night and in the daytime?

Where do most of the weather conditions in the United States come from?

What causes the "terror of the prairies"?

What is the source of the blood-red rains of Sicily?

Picture Hunt

What is a waterspout? 1–230

How can one recognize a "twister"? 1-229

Related Material

How does the wind grind Holland's grain? 6-344, 345, 352

What makes the winds blow? 1–222-25

The hurricane in Galveston, Texas, 1–72

Hurricanes in the West Indies, 7–64

Practical Applications

How have men harnessed the wind? 1–227-28

How does the United States Weather Bureau use the winds to forecast weather? 1–275-78

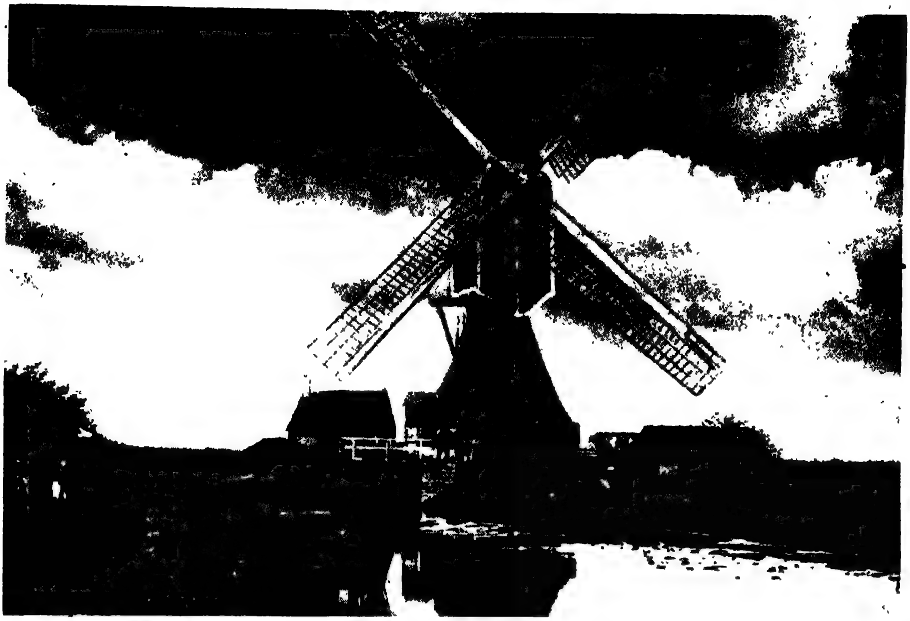
Leisure-time Activities

PROJECT NO. 1: Make a sail to help in skating, 14–44.

PROJECT NO. 2: Make a glider, 14–47.

Summary Statement

The winds carry the weather of the earth, often causing great destruction of land and loss of life.



In Holland the wind is put to work turning these picturesque mills, which dot the country everywhere. As the great arms whirl round they grind the farmer's wheat and do many other odd jobs.

BLOW, WINDS, BLOW!

The Breezes That Fan Our Farms and Cities Are Just as Useful as Those That Bring the Sailors Home from Sea

WHAT a monotonous place the world would be if we had no winds! No gentle breeze would ever come to comfort us on a stifling day. No boisterous blast would ever tumble our clothes, and tease us by tweaking our hats away or blowing umbrellas inside out in the midst of a pouring rain. And no gigantic friend, with powerful, tireless arms, would turn our windmills for us or help us fly our kites.

Of course the winds all have an uncertain temper! They are all the while veering about; sometimes the weather vane seems to be the busiest thing in town. But the gusty, changeable fellows that whistle around our chimneys are caused by the very same force as the great winds of the earth—the romantic "trade winds" and the "roaring forties." All winds, whether they work on the farm or sail the ships at sea, are at bottom caused by the ceaseless exchange of the heated air at the Equator for the colder air of the latitudes farther north and south, including the Poles. It is the never-ending contrast of temperatures, all the way from the Equator to the Poles, that starts the air sweeping and swirling along the ground.

As you know, the winds in the North Temperate Zone blow in general from west to east, but instead of roaring along at forty miles an hour they are so broken by mountains and forests and cities that it is only at a height of some three miles that they run smoothly. Near the ground they are twisted and whirled so madly that there is no telling where they will be coming from next.

Now the winds that bring us most of our weather form themselves into vast wheels,

which the weather man calls "cyclones." These must not be confused with tornadoes, those terrors of the Central United States that can destroy a sizable town in a few minutes. The real cyclone is a whirl so in the way opposite to that in which the hands of a clock go, or, as we say, "counter-clockwise." That means that on its eastern edge the wind is blowing north and on its western edge it is blowing south. The wind

Photo by U. S Weather Bur

The great cloud is a sandstorm that swept down on Midland, Texas. As wind passes over a dry country it picks up tons of sand that it often carries hundreds of miles. That is also the cause of the desert simoons.

vast and so majestic that no one over whom it passes would know the wind was turning at all. It may be a thousand miles or more across, and wherever it passes it distributes the weather that it always carries wrapped up in its circling folds. Slowly it paces along from west to east with such a regular motion that the weather man can tell, as a rule, just where it will go and just about how long it will take to get there. In this way he can foretell what weather it will deal out at any given place.

Where Do Cyclones Come From?

In the northern half of the globe such cyclones always whirl in the same direction— at the top of the cyclone blows from the east and at the bottom from the west. Such are the great whirls that you see on any map of the weather. At their center is the word "Low"—there and to the southeast it is usually raining. One after another, they frequently appear from somewhere off the coast of Alaska, follow each other south-eastward into the United States, sweep across it in the form of a great curve, and travel on out to sea along a path that leads northeast. Hot and cold, moist and dry weather comes in their wake—especially in winter. Between them are masses of cooler air—known as "anticyclones" and marked "High"—where the weather is fine;

Photos by Visual Education Service and U. S. Weather Bureau

This is the whirling funnel that sucks up houses and trees and men. In Kansas tornadoes have caused such loss of life that people have taken to building dugouts, like the one above, in which to take refuge. If ever you see a "twister" coming in the southwest and you have no dugout near, run as fast as you can toward the north or northwest. A tornado's path usually lies from southwest to northeast, and is rarely as much as a quarter of a mile wide. When the storm strikes, lie down flat on your face, in a depression if possible, with your arms stretched out ahead of you. In the inset is a picture of a pine board, 10 feet by 3 inches by 1 inch, which a tornado has driven right through a palm tree without breaking the board.

in winter the anticyclones bring us our cold waves.

Many of these cyclones cross the North Atlantic and go swirling eastward over Europe; and the southern half of the globe has its own procession of great whirls.

Typhoons and Hurricanes

But winds that get started whirling are not always so well-behaved as the ones that deal out the weather over the United States and Europe. When vast wheels of that kind form over tropical seas, they can work up a terrific speed and bring death to many a gallant ship. Such are the storms that are known as "hurricanes" on the Atlantic Ocean; and such are the dreaded "typhoons" (tī-fōōn′) of the China Sea. Hurricanes forming over the West Indies often whirl their way, first northwest and then northeast, until they reach the southern part of the United States, where they may destroy villages, farms, and cities. Luckily, the Weather Bureau is able to foretell them and warn shipping.

Photo by Am[illegible] of Natural H[illegible]

When a "twister" is formed at sea its funnel sucks up great quantities of water, as shown above. If such a waterspout hits a small vessel, it may be the end of the little craft.

The Terror of the Prairie

The most terrible whirlwind of all is the tornado. It may well start in much the same way as the little eddies of dust that spring up in the street on a windy summer's day when two opposite breezes collide and start spinning, just as you spin around when you collide with a playmate. But a tornado forms in the clouds of a thunderstorm, where the air gets whirling so fast that it forms a gigantic black funnel, the narrow end of which finally comes down to earth. The top is not often more than half a mile wide, and the whirling base that levels forest and town is usually only a few rods across.

But the speed of the whirl is tremendous—so fast that the weather man's instruments cannot measure it, though he knows that it must sometimes be more than five hundred miles an hour. No wonder it can twist up trees by the roots, pick up a house and spin it, and crush a steel bridge as if it were made of matches! It may drive a stiff blade of grass into soft wood or the bark of a tree, and has been known to leave chickens completely plucked. Sucking up dust and wreckage into its tube, the whirling funnel sweeps ahead and leaves a path of death and destruction behind it—sometimes for as much as two hundred miles. Early western settlers often had a "dugout" in which they could take refuge when a "twister" loomed up on the horizon.

If a tornado passes over a river or a lake, its tube sucks up large quantities of water. At sea this is called a waterspout, and it is sometimes powerful enough to destroy small vessels.

In various parts of the world are winds

that have developed little traits of their own and have even grown as famous as the gallant "trade winds" or the swashbuckling "roaring forties." The "mistral" (mĭs'trăl) in Southern France is drawn down from the northwest by the rising of warm air over the Mediterranean and the heated sands of the Sahara. It is a wind sung by poets and woven into the lives of the people. From a gentle little breeze that cools the weary peasants in summer it can rise to a winter's gale that will bowl a horse over. But it is dry and bracing, and brings a sparkling sky.

Below the arrows show the direction of the sea breeze that springs up in the daytime on almost any coast. It is caused by the rising of hot air over the heated land, and the consequent flowing in of cooler air from the sea, which does not get hot so fast under the sun's rays.

Southern Asia has its famous "monsoons" (mŏn-sōōn'), which for six months of the year blow from the land out over the sea and for six months in the opposite direction. In fact, the word "monsoon" means "season," and the name has been given these winds because they blow with the seasons. During the winter, when the land is cold, the air above it is drawn seaward by the rising of warmer air over the Indian Ocean. This makes a cold, dry wind. But when the sun is high enough to heat the land till it is warmer than the sea, the wind turns about and begins marching inland. It is a dramatic moment—this turning of the monsoon—for all the people in those hot lands. For the sea wind brings them rain to grow their crops, and so carries in its bosom life or death for India's crowding millions.

The same thing happens on a small scale every day along nearly all seacoasts. Under the rays of the sun the air above the land is warmed until the cooler sea air pushes it up and rushes inland for a few miles. For the land is always heated more rapidly than the sea. But it cools more rapidly too. So during the night there comes a time when the sea air is warmer and is forced to rise by the pressure of colder and heavier land air. Then the breeze wheels about and goes rushing out to sea. So the sea breeze is a day breeze, and the land breeze a night breeze.

Out in the Rocky Mountains there is a west wind known as the "chinook" (chĭ-nōōk'), supposedly named from an Indian word meaning "snow eater." When it starts to climb the western mountains it is loaded with moisture. Then it cools on top of the heights and drops its vapor in the form of rain or snow. When it comes down the eastern slopes it is a warm, dry wind that heats the earth and turns broad acres that would otherwise be too cold to bear crops into the rich farm and grazing lands of Alberta, Montana, and Idaho. A wind of much the same kind climbs over the Alps in Europe and warms the lands upon the other side.

As soon as the land cools off at night, a land breeze springs up at sea. For the water is much slower to change its temperature than the land is, and so keeps the air above it warm long after the land and its air have cooled. As the night advances and the air over the land gets colder and colder, the warm sea air is forced up by the heavier cold air beside it. This sets up a current of air flowing out over the sea.

A Wind From the Desert

There is another dry, warm breeze less welcome to the people who feel it. This is the famous "sirocco" that blows from off the Sahara, carrying a fine red dust sometimes as far north as Sicily. When chilled

Photo by L. Olivier

A sandstorm in the desert brings terror to man and beast. At its approach the camels are made to kneel, and beside them their masters take shelter, with faces covered to keep out the smothering dust. We who live beside green fields or on the paved streets of a city, have no idea how blinding such a storm can be.

it gives up its moisture, and sometimes drops blood-red rain—so heavily has it been loaded with ruddy desert sands!

All deserts have fierce dust storms—or simoons (sī-mōōn′)—before which men and animals must crouch and turn their backs until the fury is past. On the Colorado Desert they blow sometimes as hard as seventy-five miles an hour. A large part of China has been turned into a blooming garden by terrible winds from off the Gobi Desert that have made up for their violence by scattering fertile desert soil wherever they blow. The "Santa Ana" of Southern California is really the edge of a desert simoon.

In the United States a west wind usually brings us fair weather and an east wind rain or snow. Sometimes southerly winds may bring storms, but by no means always. If a north wind shifts to the east you may look out for a cold storm within twenty-four hours. South winds are usually moist, west winds usually dry and often dusty, and northwest winds dry and often cold.

Our winds can blow, too, in a good many different moods. A breeze just strong enough to flutter the leaves of the trees is coming at only three to five miles an hour. At thirteen miles an hour it can raise coarse dust, and at nineteen rock the tree tops. Only a strong man can walk in the teeth of a forty-mile gale; so you can imagine the power of a wind in New York City that once blew at ninety-six miles an hour.

But no matter where it comes from or what it brings us, the restless wind is one of the most impressive and romantic things in all the outdoor world. How tame the world would seem without it!

Reading Unit
No. 8

TRAVELING MOUNTAINS OF THE SKY

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How many kinds of clouds are there? 1 234-35
How may clouds help us to predict the weather? 1–235
What are clouds composed of? 1 235
What causes beautiful sunsets? 1–235
At what altitude do we find clouds? 1–236
What is meant by a cloud's silver lining? 1-236
What kind of cloud is the rain maker? 1–236

Things to Think About

How do clouds serve the earth?
How do clouds form?
What is meant by the statement: "A dark cloud is already raining; a white cloud, in the Indian's phrase, is 'rain not yet.'"
Why do the loveliest clouds bring rain before long?

Picture Hunt

What different kinds of clouds do you find here? 1 236-37
What usually happens in the air above an erupting volcano? 1–235

Related Material

How has weather influenced civilization? 1–193-97
How may the water in the air cause a rainbow? 1 271
What happens to the moisture in the air when winds carrying it are unable to cross the Rocky Mountains? 1–255-56
How do plants let water vapor escape into the air? 2–51, 53
How does our food supply depend upon the clouds in the air? 2–40-46, 49, 53

Practical Applications

How may the different kinds of clouds help us to predict the weather? 1-235-37
How do fruit growers protect their plants against frost? 1–237

Leisure-time Activities

PROJECT NO. 1: Watch cloud formations and see if you can name the different kinds of clouds, 1-236-37.
PROJECT NO. 2: Predict the weather according to the clouds and check your prediction with the daily newspaper and radio weather reports, 1-236-37.

Summary Statement

The clouds are great reservoirs of moisture that may fall as rain or snow.

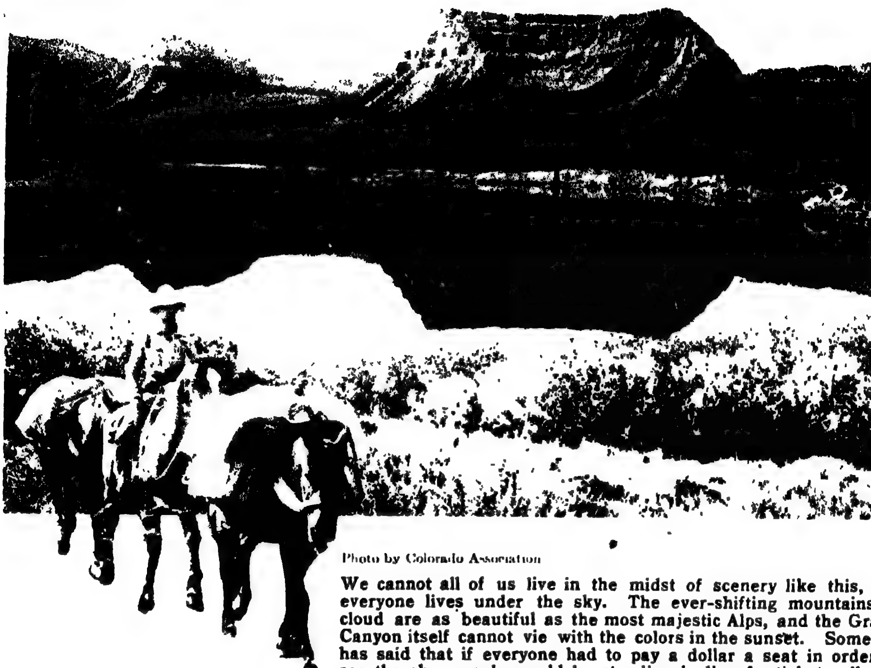


Photo by Colorado Association

We cannot all of us live in the midst of scenery like this, but everyone lives under the sky. The ever-shifting mountains of cloud are as beautiful as the most majestic Alps, and the Grand Canyon itself cannot vie with the colors in the sunset. Someone has said that if everyone had to pay a dollar a seat in order to see the sky, people would be standing in line for tickets all day long, and would not feel the price too high.

TRAVELING MOUNTAINS *of the* SKY

The Clouds Are So Light That They Float in the Air, and Still They Send Down Tons of Water to Us

LUCKY is the man who has learned to look at the clouds. Ever changing, always beautiful, they never fail to fascinate anyone who will take the pains to look skyward. But of course we must know something about them if we are to find out how interesting they are. That is always the way with things that are really interesting—and that is the reason why people who are wide awake get so much more out of life than people with sleepy minds. They are not afraid to rummage about among the interesting things with which this old world of ours is crammed so full. As a result, their lives are always full of adventure, even if they do not stir more than twenty miles from home.

But clouds, you will say, are always about alike white things that float in the sky and sometimes send us a rain!

There never was a greater mistake. There are so many kinds of clouds that over a hundred varieties have been classified, and each one of them tells the weatherwise person something about the state of the weather. That is where the fun comes in!

For though the weather man may be very useful in forecasting the general conditions to cover a large territory, he does not attempt to tell what the weather will be in any particular spot.

Why We Should Watch the Clouds

That is where the person who has his eyes open and uses his wits can specialize on the information given by the professional weather man, and can often foretell just what is going to happen right around him in the next ten or twelve hours. To be sure, this kind of skill is very much less common than it used to be, when people had no Weather Bureau and were more dependent upon the weather. But of course that merely means that people nowadays are always discussing the subject without really knowing much about it. How much more interesting life would be if, instead of always complaining and never finding anything out, we should put our wits to work and learn to be good weather prophets.

Let us suppose that we are all going to look upon the weather as a matter of intelligent interest—something always at hand to be watched and something in which the humblest of us may become expert. One of the first things we must learn is to read the face of the sky.

What Is a Cloud Made Of?

And that means that we must make friends with the clouds. For those fleecy white masses that sit lazily on the horizon or scud along on the wind are really gigantic reservoirs to hold the moisture that is going to fall as rain or snow sometime. As you already know, all outdoor air carries tiny particles of moisture that we call water vapor; and when the air is chilled, those bits of water gather together in larger droplets—or, as we say, "condense." When water vapor has condensed, we can see it floating in the shape of clouds, sparkling on the earth as dew, or falling from the sky as rain or snow. But any water that falls from the heavens has first floated in a cloud. Or, to put it another way, it has risen from the earth as invisible water vapor in some mass of warm air that has been pushed up by heavier cold air all around it. And when the warm air has risen far enough to be chilled in the cold upper atmosphere, its invisible water vapor has gathered itself together—or condensed—into cloud.

Photo by American Museum of Natural History

When a volcano such as this one is in action, it belches forth great quantities of smoke and dust and steam that, rising into the air, form a cloud above the crater's mouth. Sometimes smoke ascends slowly for quite a long time before the actual explosion, and spreads out into the shape of a gigantic pine tree above the crater. And sometimes volcanic dust is blown long distances, and causes beautiful sunsets all the way round the world.

Now there are four great kinds of clouds, each of them easy to recognize and each of them telling a very clear story of what is going on up aloft. First of all are the "cirrus" (sĭr′ŭs) clouds, those delicate, feathery wisps that are always gleaming white and always highest in the sky. They are named from the Latin word for "curl" or "wisp." In extreme cases near the Equator they may be as far up as eleven miles. Their moisture has condensed into tiny ice crystals. Such clouds are very far from ready to send down rain. Indeed, they are too lacy to hold the gentlest summer shower. But they can foretell the weather. Moving

from the southwest they usually indicate a falling temperature, and moving from the northwest they show that the temperature will probably rise—and they are the first heralds of an on-coming rain.

How High Are the Clouds?

Next come the "cumulus" (kū'mū-lŭs) clouds, great white masses that look like cauliflowers or woolsacks, rounded at the top and always in motion. Their name is well taken from the Latin word for "heap." Like snow-capped mountains they often tower five miles up in the summer sky. Such glistening masses are formed by updrafts of warm air that chill when they get to the colder upper levels and reach the condensation point. The moisture forms into tiny particles that gleam in the sunlight and grow denser and denser as more and more air mounts. When they rise four or five—and sometimes even eight—miles into the air, such clouds become "thunderheads" and often bring thunderstorms. Finally they break up and drift away—they are scattered into thin air and their usefulness is over.

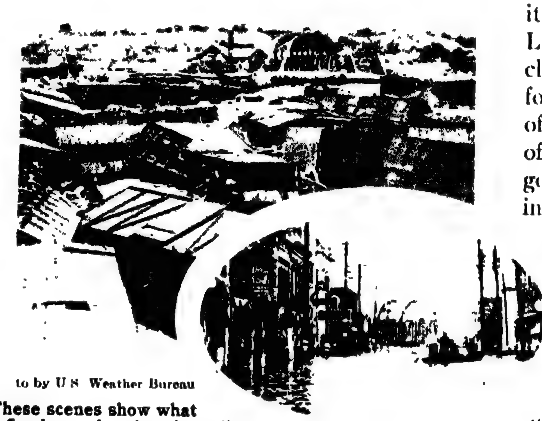


Photo by U S Weather Bureau

These scenes show what a flood can do when it really sets to work on the business of destruction.

How a Cloud Gets Its Silver Lining

A third kind is the thin flat cloud that covers the sky like a ceiling. It is given the name of "stratus" (strā'tŭs) from a Latin word that means "a spreading out." Clear across the sky it stretches, from horizon to horizon, and often shuts out the sun completely, though sometimes it is so thin that we can see his shape through it. Often it is spread, in breaking up, over only a part of the sky, and then we see it in great magnificence reflecting the light at sunset from its under side. For it is reflected sunlight that gives a cloud its silver lining.

Stratus clouds are formed when a broad layer of air rises into the colder upper levels without being disturbed, and in cooling condenses its moisture into a blanket that rests peacefully in the sky. Such clouds never send us rain unless they are chilled yet further.

It is the "nimbus" (nĭm'bŭs) cloud that is the rain maker. It is the dark, heavy cloud often seen at the base of a mass of white thunderheads. At other times it moves majestically up over the western horizon until it darkens the sky and lets fall the rain or snow it carries wrapped in its thick mantle. Like the cumulus cloud it is usually formed on the top of a rising column of air, but it has gone much farther in the brewing of rain than the cumulus cloud has. Indeed, "nimbus" is from a Latin word meaning "rain-storm," and rain is actually falling from a nimbus cloud, which is always very low. Sometimes wind comes with such clouds, but clouds never hold anything but moisture.

Perhaps you have already noticed that the blacker the cloud the more likely it is to bring rain. Clouds are light or dark according as the droplets in them are large or small. The larger the drop, the darker the cloud—and the nearer it is to raining. One weatherwise man has said, "A dark cloud is already raining; a white cloud, in the Indian's phrase, is 'rain—not yet.'"

Clouds That Look Like Sheep

There is another cloud form that we ought to know because of its beauty. It gives us what is commonly known as a "mackerel" sky—one in which little fleecy clouds four

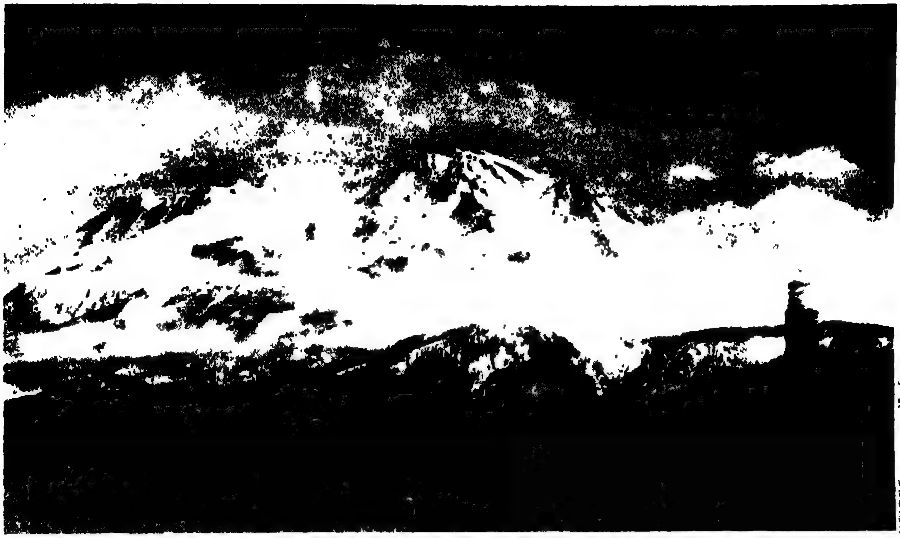


Photo by Rock Island Ry Co.

It is a bit hard to tell in this picture just what is mountain, what snow, and what cloud, for the moisture that will later fall as rain or snow, often floats as a cloud around a mountain top. Of course to the people living there it is only fog, for even a dense cloud may seem thin, once one is in it.

or five miles high are ranged along the heavens like flocks of sleeping sheep, all lying in even, quiet rows. The learned man calls them "cirro-cumulus" clouds, by which he means that they are cirrus clouds that have taken the shape of small cumulus clouds; that is, they have arranged themselves in little "heaps." They make one of the loveliest of all skies—and one which commonly brings rain before long. Eddies of wind are what lay the cloudlets in such even rows.

Not only by bringing our rain and snow do the clouds serve us. They also help to regulate the heat. By protecting us, with their tiny droplets, from the too-steady rays of the sun, they keep the earth from getting over-dry; and by acting as a blanket at night, they keep it from giving off too much of its heat and getting unduly cold. All this is of great benefit to growing things.

When to Look Out for Frost

It is the clear nights that are likely to be frosty, not the cloudy ones. There can be no frost or dew on a cloudy night, because the clouds do not let the heat escape, and so the temperature stays too high for frost or dew to form. But if the temperature at nightfall is below 40° F. and the air is clear and still, it is time to protect all the delicate things in the garden that you wish to keep unharmed. The frost usually forms about two hours after midnight. Sometimes it is on grass but not on bushes or trees, for the air a few feet from the ground has not fallen below freezing. On a very cold day we may see frost on the windowpane, even though the room is quite warm. It has formed because the outdoor air is so cold that the temperature of the glass falls way below freezing and turns the moisture touching it into fairylike designs in frost.

If it is the season of the year when fruit is hanging on the trees, the weather man sends out a warning to the fruit growers on nights when frost is threatening. To save his valuable crop the grower then lights fires all through his orchards. They burn all night, and keep the air just warm enough so that the fruit can come through in safety. But on cloudy nights this is not necessary, for the clouds keep the warm daytime air from escaping into the upper atmosphere.

Reading Unit No. 9

WHERE THE RAIN COMES FROM

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How does water get into the air? 1–239

How may we increase the amount of water that air will hold? 1–239-40

When does air reach its saturation point? 1–240

What is meant by relative humidity? 1–241

What is fog? 1–242

What causes fogs on land and on sea? 1–242

Things to Think About

What is the difference between rain and dew?

How does humidity affect comfort?

How much water is necessary to form a fog?

How do dust and electricity help produce rain?

Picture Hunt

Where would you go if you wanted to be able to look down on the upper surface of a cloud? 1–241

Why is there snow on this mountain top in the tropics? 1–242

Related Material

How much rain falls each year in Africa? 5–443-44

How does rainfall affect plants? 2–193

What does rainfall have to do with the plant and animal life of a region? 5–444

How much rain falls each year in the United States? 1–89

How do streams get their supply of water? 1–48

What is the yearly rainfall in the tropics? 2–196

How is humidity measured? 1–393

How do ships navigate in fogs? 1–237, 241-42, 407, 10–229

Practical Applications

How is indoor humidity kept at a proper level? 1–393, 409, 9–22

How does humidity affect health? 1–241

Leisure-time Activities

PROJECT NO. 1: Make a rain gauge, 14–48.

PROJECT NO. 2: Show the presence of vapor in the air, 1–240.

Summary Statement

The water vapor in the air is constantly renewed by evaporation from the earth, and condenses to form rain, snow, hail, fog, and dew.

From Frederic Lewis, photo by Harold M. Lai

The tops of these heaped-up cumulus clouds are bright with sun, but if you look at the dark nimbus cloud hanging low in the sky, you will see that rain is pouring down from it in great sheets.

WHERE *the* RAIN COMES *from*

No Matter How Clear the Air, It Always Has Water in It. What Brings the Water Down as Rain?

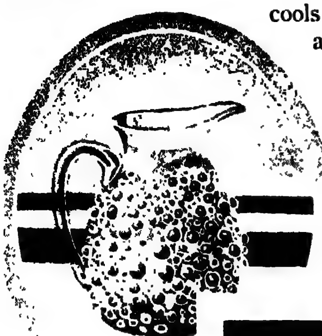
HAVE you ever asked yourself where the rain comes from? The air on a given day seems like any other air, but all at once gallons and gallons of water will come tumbling out of it. People tell you it comes from the clouds, but that is a puzzling answer. Why did it stay in the sky at all with nothing to hold it up?

The truth of the matter is that there is always water vapor in the air. Whenever we are outdoors we are breathing a certain amount of it in and out of our lungs. It floats in very tiny particles, even above deserts, and reaches upward certainly seven or eight miles. We never know it is there, though in heated rooms, where the air is too dry, we soon feel uncomfortable. Everything moist—oceans, rivers, lakes, and all living things—is constantly giving off water vapor into the air.

When air is warm a good deal more water vapor can enter a given space than when it is cold—at summer temperature five or six times as much as at freezing. In a medium-sized living room comfortably heated there would probably be some five teacupfuls of water. But if the temperature should drop to freezing, the space could hold only one teacupful.

Now what would become of the other four cupfuls of water? It would have to collect on the walls and windows and furniture—or, as we say, it would have to condense. That is what has happened in the cellar on a hot day in summer, when the stone walls are dripping with moisture. The

moisture has condensed. It is what happens whenever you bring a glass of ice water into the room on a hot day, for the cold water cools the vapor around it so much that the moisture condenses and turns from a gas into beads of water on the outside of the glass.



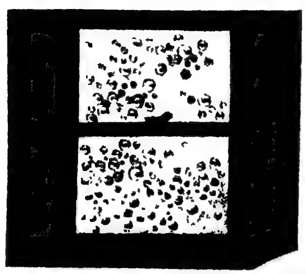


Photo by Bentley

All of these pictures illustrate water condensing at what we call the "dew point," though of course it is only the lowest picture of all that shows us dew as it has formed out of doors on a blade of grass. The moisture has gathered on the outside of the pitcher because the water inside it was cold enough to chill the air around the glass. The air in the room contained tiny particles of moisture, called water vapor, and when the air around the pitcher fell to the right temperature, these tiny particles condensed into drops of water on the pitcher. That is what makes any pitcher of ice water "sweat" in a warm room; the moisture in the air has condensed upon it. It is the same thing that makes moisture gather on the inside of the windowpane on a winter day, when the glass is cold enough to chill the air near it to the "dew point," at which the moisture in the air condenses. And it is the same thing that makes moisture gather on blades of grass at night, when the air near the earth grows so cold that its moisture condenses on all the foliage and forms dew. From all this you can see that real dew never "falls"; it just gathers.

The point at which this happens we call the "condensation point"—for it is then that the water vapor "condenses." When a given space has as much vapor as it can hold without dropping it—so much that the slightest cooling would start condensation—we say that the vapor is saturated" (săt'ū-rāt'ĕd), or that the "humidity"—or moisture—is 100%, or that the vapor is at the "dew point." We call it the dew point because it is then that dew forms with the lightest cooling of the air. The point at which it occurs depends on the amount of moisture in the air. The dew point in dry air is much lower than in damp air.

Rain and snow fall from the sky, but dew does not. It forms in exactly the same way as the beads on the glass of ice water. But it is not long that men have realized this. Until only a little more than a century ago, they thought the dew fell from above, and accounted for it in various poetical ways. Its ancient names were "star water" and "star tears." Later, people came to believe that it was the breath of goddesses or of angels. Now we know it is the breath of our own old Mother Earth. For during the day the sun draws moisture out of the ground, and when night falls and the twigs and flowers and grasses grow cool, they chill the vapor that touches them, sometimes to the point of condensation. Then the air gives up a part of its moisture in delicate beads on all the grass and flowers. In this way the moisture that Mother Earth breathed out in the heat of the sun is given back to her at night.

The sight of those sparkling jewels is the reward of all who rise early. No one who has seen the fairylike wheel of a spider's web on a dewy morning in summer can fail to feel repaid for his hour or two of lost sleep. For sluggards arrive after the sun has already drunk up again all the tiny droplets that the night distilled—water so delicately made that it is the purest to be found in nature. In dry weather dew is of enormous value to plants; sometimes they are forced to rely entirely upon it.

If the surface on which water vapor condenses is below the freezing point, we have, not dew, but frost.

Photo by Edward Ratcliffe

From the top of the RCA Building in Rockefeller Center the camera has caught some of New York's famous skyscrapers as they floated in a sea of low-lying cloud. At the right is the 1,250-foot Empire State Building, tallest in the world. With it as a yardstick you may estimate the depth of the cloud.

Two or three times a day the weather man measures the "humidity" (hū-mĭd'ĭ-tĭ), or the "wetness," of the air. When he says, for instance, that the humidity is 50%, he means that there is just half as much moisture present as there could be at the temperature at which the measurement was taken.

How Humidity Affects Us

All outdoor air contains moisture. It is only in our houses in winter that the air gets nearly dry. And that is very unnatural and very bad for health. It is one reason why people are ill so much more in winter than in summer. If everyone would take pains to see that there is always plenty of moisture in the air in our homes, we should have to spend very much less time in bed with colds and influenza.

But if the air is too damp we are uncomfortable, for then perspiration cannot evaporate; if the weather is warm we feel all the warmer, and if it is cold we feel all the more chilly.

No one will be surprised that the water vapor in the air has a great deal to do with the weather. But it will be harder to believe that dust has just as much effect upon it. Not the dust that settles on tables and chairs, but a fine, invisible powder that is everywhere in the atmosphere! The reason why dust is so important is that every tiny droplet of water in dew or rain or fog must have a center to condense on before it can form. The tiny dust particles act as such centers, and so do still tinier electrified atoms known as "ions" (ī'ŏn). Without any of those useful little cores, we should never have dew or gentle rain, or mist or fog or cloud! Our rains would become terrific downpours, to the great discomfort of all growing things.

How Fog Forms

Though all water vapor must have dust or ions to condense on, it can take a good many different forms, once condensation has started. It may turn into rain, hail, snow, mist, cloud, fog, frost, and dew. Of all these, the one we probably see oftenest is cloud or fog—for they are very much alike, though there are certain differences. In general, a fog may be described as a cloud

that rests on the ground. Its particles of vapor are very small—perhaps two ten-thousandths of an inch through.

How Much Water Is in a Fog?

Indeed, it is amazing how little water is needed to make a fog. A single gallon can make a cubic mile of air so dense that all commerce is brought to a standstill. A few quarts of water spread through the air in tiny, invisible specks can paralyze London for several days and cause a loss of millions of dollars. Of course a city fog is made worse by the smoke that gathers in the air. The thousands of chimneys that pour forth soot are furnishing billions of particles of dust on which the droplets can condense. Sometimes all that is needed is a slight fall of temperature for the moisture to weave a veil behind which towering skyscrapers look like ghosts and the lights are misty blurs. If the temperature rises, the fog will often disappear again, turned back into water vapor. If the air gets colder, the fog may rain itself away. But the oily smoke coats every tiny water particle with a greasy film which makes it hard for the particles to unite and fall in the form of raindrops.

Fogs That Hover over the Sea

It is at sea that fog is most dangerous. There it is the one form of weather that man has never conquered. It may blanket hundreds of square miles—so densely that ships do not know of one another's presence until the very moment they collide. Of course a ship always blows its great horn in a fog—for five seconds every minute. But *even so, hundreds of lives are lost in fogs.* The danger of hitting an iceberg is far greater in a fog, and icebergs have no horns to blow. To avoid such accidents a vessel sometimes takes soundings from time to time to find out the temperature of the water, for an iceberg cools the ocean round it for a short distance. Sometimes a very large iceberg will reflect the sound of sharp blasts from a siren and in that way show its presence.

Aviators, too, dread a fog. They can soar above a low fog, but not above high ones. If they try to mount above them, the air may grow so cold that particles of water freeze to the plane and form a coating of ice which adds weight and disturbs the air flow over the wings, and finally brings the plane down.

Great Fogs of the Grand Banks

Fogs at sea come about in a somewhat different way from those that form over cities. When warm moist air floats over currents of cold water, it is chilled and its moisture condenses into fog. Over the Grand Banks of Newfoundland this is constantly going on, for moist air from the warm Gulf Stream drifts over the cold waters brought down by the Arctic currents and is rapidly cooled. As a result, all that part of the Atlantic Ocean is a perilous place for the ships that go there to fish or pass by on their way between America and Northern Europe. Many a boat lies at the bottom of the sea off the Grand Banks.

Perhaps some day mankind will learn to conquer fog, but at present we are helpless before it.

In the cold air above this peak in Chili, moisture has formed into snow, though it is summer in the lowlands.

Reading Unit
No. 10

UP IN A RAIN CLOUD

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts consult the Richards Year Book Index.

Interesting Facts Explained

When does the moisture of clouds turn into rain? 1–245
What is a raindrop? 1–246
What is the cause of thunder and lightning? 1–246-48
How fast does thunder travel? 1–247
What kind of cloud tends to produce thunder and lightning? 1–244-47
Where does lightning tend to strike? 1–247-48
Why are skyscrapers fairly safe during an electric storm? 1–247-48

Things to Think About

How does a raindrop form from water vapor in the air?
How are hailstones formed?
What substances permit electric current to flow through them most readily?
How does the temperature of rising air change?

Picture Hunt

What changes does water go through in turning from cloud to rain? 1–244
How can scientists make rain fall when conditions are right? 1–245, 247, 249

Related Material

What form of energy does lightning represent? 1–340
What experiments did Franklin perform with lightning? 12–465, 14–500
What did Franklin invent to protect buildings against lightning? 12–465
What causes an electric spark? 1–513
What are conductors and insulators? 1–247, 514, 10–106
What is meant by the electron theory? 1–499
How may electricity similar to lightning be produced? 1–494, 495, 496

Practical Applications

How are tall buildings protected against lightning? 1–248
What should a person do during an electric storm in open country? 1–248

Leisure-time Activities

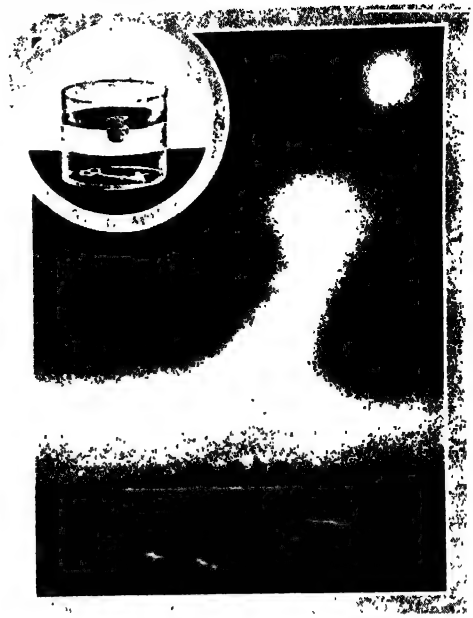
PROJECT NO. 1: Produce a cloud from the spout of a kettle of boiling water, 1–244.

PROJECT NO. 2: Estimate how far away lightning is being discharged during a thunderstorm.

Summary Statement

The chilled water vapor in a cloud forms drops of water or snow which fall when they become heavy enough.

The life history of a raindrop! Under the sun's rays the land and sea are always giving off moisture into the air, just as a boiling kettle does.



In some places the air grows very hot, and, like a cork in water, is forced to rise by the cooler, heavier air that flows in around it from all sides.

As the air mounts it is chilled, and its moisture begins to condense into droplets around tiny particles of dust that are always present. This forms a cloud.

Finally these tiny droplets join hands and get so heavy that they start racing down to earth in the form of raindrops. Then we have a shower.

Courtesy Florida State News Bureau

Scientists have learned to make rain in these strato-cumulus clouds fall when and where it is needed. The experimenters Langmuir and Schaefer knew that in nature a drop of rain will start with an ice crystal as its core or nucleus. This core gathers moisture into snow-flakes which fall when they get too heavy for the cloud melting into rain as they come down to earth. By chance the scientists found that dry ice pure carbon dioxide put in the freezer of a refrigerator would cause a miniature snowstorm of ice crystals. This gave them the idea of using tiny pieces of dry ice to make storms in moisture-laden clouds. When clouds like those above have piled up in the sky high enough to reach a temperature of —38° F. the point at which ice crystals form -small pellets, or "seeds," of dry ice are thinly scattered above them. Like the natural crystals, those seeds gather up moisture into large snowflakes, which finally grow so heavy they fall out of the cloud. As they descend through warm, damp air they melt and come to earth as rain.

UP *in a* RAIN CLOUD

Where There Are Forces That Will Polish Off a Hailstone or Hurl a Great Thunderbolt

MOTHER NATURE has a good many ways of watering her garden, for she is a thrifty old dame and never lets even a drop of moisture go to waste. Whatever water the warmth of the sun steals away from the earth has to be given back again whenever the air is chilled enough to make the moisture condense and fall. As we have already seen, water vapor may condense into fog and cloud and yet stay floating in the air, though just how it manages to do so we cannot always tell. Often, of course, the particles are exceedingly small, and the updrafts that carried the vapor aloft continue to keep the cloud there. But clouds are heavy and lazy, and tend to drop their moisture whenever they get a chance. When this occurs we get rain and snow.

Now any updraft of air is sure to be chilled, for as it climbs higher and higher there is much less air pressing down upon it and the mounting air has a chance to expand -or spread out. All gases that expand lose some of their heat; so as the mounting column of air gets thinner and thinner it gets colder and colder. Then, too, as it rises it enters levels of air that are much colder than those near the earth. When it reaches the condensation point its moisture gathers together into a cloud — made up of tiny droplets of moisture, each

one with a speck of fine, invisible dust at its core.

How a Raindrop Is Made

But it is not until the droplets in a cloud have grown to raindrops or condensed into snowflakes that they are heavy enough to fall to the earth. One small droplet joins hands with others as it slowly sinks and finally gets so heavy that even a strong updraft cannot stop it. Then it comes racing down. The large raindrops that usher in a storm may for a moment become a quarter of an inch through, though as a rule their own rapid motion breaks them in their long tumble earthward. An ordinary raindrop is less than a tenth of an inch across. It is when billions upon billions of such drops fall helter-skelter to earth that we have a shower.

So rain is frequently caused by an updraft of air which cools when it gets high above the earth and flowers into billowy clouds on its summit. Sometimes mountains force a wind to rise and cool, sometimes cold air pressing in at the sides starts a column of warmer air upward. Always, in some way or other, before a rain can start, warm moist air must have risen and cooled. All this explains why cold north winds are likely to bring, not rain, but clear weather. They are not cooling the warm air that lay over the earth to start with—they are driving it away. They would have to be chilled yet more themselves before they could shed their moisture. And this explains, too, why the windward side of mountains is usually well watered but the other side much less moist.

In winter it is the great cyclonic whirls that distribute moisture over North America. But in summer they have less effect. Rain then is brought about by the rising and chilling of columns of warm air that have been heated by the sun-baked earth—and those are what bring us our electric storms. When the rain falls, it chills the lower layers of air as it passes through them, so we say that a thunderstorm "cools the air."

Photo by U. S. We

Here are two kinds of lightning, white and black! But the sight was never seen by any human eye, for it does not exist in nature. It is only a trick of the camera. The picture is worth looking at closely, however, for the flash that is outlined in black is much more distinct than the other one, and shows all the delicate tracery of the discharge.

Have you learned to enjoy a thunderstorm? Many people are afraid of one all their lives long, and never know the thrill of delight that others feel at watching one of the most magnificent and dramatic sights in nature. Luckily, few of us will ever see the eruption of a volcano or feel the terrible power that a tornado can let loose, but a thunderstorm is only a little less magnificent to see, and is really almost harmless How many people have you ever known who were struck by lightning? For the most part, the crowded traffic in a city street daily puts many more lives in danger than all the storms that pass over a spot during the course of a lifetime.

Of course it is the lightning that does the damage and not the thunder—though it is the noise that makes many people afraid. Those enormous discharges of electricity that go zigzagging through the heavens are thought to be a result of the shattering of raindrops—all of which carry electricity —by the powerful updraft in a lofty cumulus (kū′mū-lŭs) cloud, or "thunderhead," in

Courtesy Pan American World Airways

This shows you how clouds float in the sky at different levels. Low at the left, cottony cumulus clouds are massing into a stratus or ceiling formation. High above them drift the wispy cirrus clouds we sometimes call "mare's tails." There is no threat of immediate rain in the cirrus clouds, but the low cumulus clouds might be made to rain. Dr. Bernard Vonnegut found that particles of silver iodide could be made to fool near-by clouds. A smoke generator on the ground blows silver iodide dust into the air, where it hangs until a cloud absorbs it. When the temperature of this cloud falls a few degrees below freezing, its moisture gathers into snowflakes around the silver particles, mistaking them for ice crystals. The flakes grow heavy and fall to earth, melting on the way. This method of rainmaking needs no very cold clouds.

which rain is being formed. Certainly it is inside its mysterious folds that in some way electricity is manufactured.

The tremendous discharge that finally flashes toward the earth or toward another cloud is, to all intents and purposes, like the spark you get when you stroke a cat on a cold, dry day in winter. And the splitting clap that follows the flash has the very same cause as the gentle snap that accompanies your little spark in the cat's fur. But the great "spark" up in the sky has followed so long a path that the sound —which travels much more slowly than light—cannot reach you all at once, as the sight of the flash can. It comes to you in a prolonged roar—and then is echoed and re-echoed by buildings and hills and clouds till it dies away in a murmur.

When the flash and the clap come at the same instant, the lightning is near at hand. And the length of time between them will tell you how far away the storm is. For while the flash reaches you immediately, sound can travel at a rate of only a mile in some five seconds. So if you can count to five slowly between the lightning and the thunder, you may figure that the flash was a mile away—if you can count to ten, it is two miles away. Count a little more slowly than your pulse beats.

Where the Lightning Strikes

Now electricity has a great preference for certain kinds of paths. For instance it very much dislikes rubber and will not travel through it—so we say rubber is a "nonconductor." But it can make fine progress through metal—such as a copper wire—so we say that copper is a good conductor. Wherever electricity flows, it takes the easiest path. So when great currents of it are darting about through the heavens, they will always flow in the direction that

is easiest. If any tall object—a flagpole, a church spire, or a tree—is reaching into the sky, the lightning will be apt to follow it to earth, since it is nearest at hand. Most of the people who have been killed by lightning have met their death because they ran to shelter under a tree—and the tree was hit, as trees are apt to be. And cows are more foolish about this than people.

So if you are caught outdoors in the open country during a severe thunderstorm, get away from all trees and lie down flat on the ground. There you are practically out of danger. But if you are near shelter, the best thing is to go into the house, shut the windows and doors, and not go too near metal piping. Then nothing is likely to harm you.

Strangely enough tall buildings that are massed together in cities seem to be in little danger of being struck. It is the building that stands alone—the church spire or the house on a lofty hill—that seems to attract the storm. But even it can be protected by means of lightning rods. Those long metal fingers, reaching into the sky, coax the electric current to follow them into the ground — or, at other times, discharge a current into the air that neutralizes the electricity

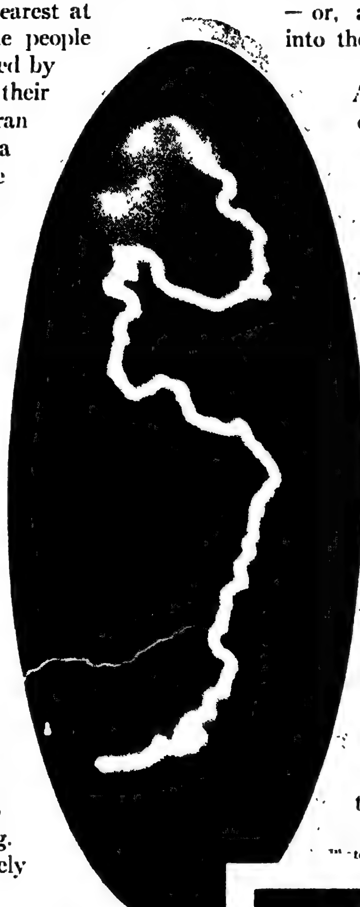


Photo by U. S. Weather Bureau

Lightning often follows strange paths, and no one knows why it sometimes strikes where it does; but we have learned that there are certain sure means of protection against it. If the building in the oval had been properly fitted with lightning rods, the bolt that is striking it would have followed the rods into the ground instead of striking the building. The church was properly protected, so the discharge did it no harm. Skyscrapers are safe because their steel frames carry the electricity safely to earth.

An aviator, of course, can take none of those precautions. Since the cloud in which the lightning plays may reach seven or eight miles above the earth, he cannot mount above it. His best chance is to turn aside and try to avoid the center of the storm.

Most lightning flashes follow a path a good deal like the course of a river on the map. The long, saw-toothed zigzags that illustrators like to draw have never been seen. The "sheet lightning" common on warm summer evenings when no storm is anywhere at hand probably comes from very distant flashes reflected by the clouds. Scientists are still greatly puzzled by "ball lightning," of which they never have been able to get a photograph. Anyone who sees one of those slow-moving globes of fire should watch it as carefully as possible and send the Weather Bureau a painstaking description of its appearance, including all surrounding conditions down to the smallest detail. For it is only with the aid of all the facts possible that ball lightning can be explained by the scientists.

Thunderstorms probably do not happen at the Poles, but nearly everywhere else in the world they set off their batteries whenever a warm, moist updraft forms into clouds in which electricity is set free. They

are most numerous in the Tropics. Occasionally we even have them in winter, but usually they come in June, July, and August. When a hot summer afternoon becomes oppressively still and "cauliflower" clouds mount high into the air, look out for lightning and thunder before long. But you need never expect them on a windy day, and rarely in the morning.

How Hailstones Are Made

Often a thunderstorm pelts the earth with hail—little marbles made of snow and ice, sometimes no bigger than coffee beans and sometimes the size of eggs. When they come hurtling down from half a mile or more in the sky, they can do terrific damage to crops. As a rule there are hardly enough of them to cover the ground, but in Southern Europe they have been known to keep falling until several inches deep.

They are altogether different from sleet, the little frozen raindrops that sometimes fall in winter. For hail is always made up of layers of ice and snow. When a raindrop on its way to earth is frozen and then sent up again on the top of the powerful updraft that is causing the storm, it sometimes meets snow—very far up in the air. A layer of snow forms around the core of ice, and the heavy little ball starts down to earth again—gathering another coat of water that freezes to ice on the way. It reaches us as a small hailstone. But if the updraft is powerful enough, the little marble may be juggled back and forth, each time adding a new layer of snow and of ice, till it gets to be of considerable size. When it finally comes to earth it is made of layer upon layer much like the "bull's eye" candies that have such an amazing variety of color between the outside and the core.

Hailstones usually come near the beginning of a thunderstorm, when the updraft is strongest. Luckily a hailstorm lasts only a few minutes and covers a very small territory so the damage it causes is not widespread. And the stones never stay long on the ground. Like so many natural marvels, they must be examined quickly. For Nature does not stage her effects for sleepy heads, as a rule.

A third method of rainmaking needs no clouds with freezing temperatures. This process is called "chain drop reaction." Into clouds that have strong upward currents, as this towering cumulus cloud has, an airplane sprinkles a few large drops of water. The rising air currents hold the drops of water while they collect the droplets of moisture in the cloud. Soon the enlarged drops break up, making new drops which also begin to collect droplets. The growing and breaking process continues until the cloud is full of large drops, which then fall to earth as rain.

Rainmaking has other uses besides watering parched crops and ending droughts. By seeding clouds containing sleet, scientists expect to prevent the formation of hail, which ruins whatever tender plants it hits. Besides, they hope to prevent some of the many forest fires started by lightning. To do this they will seed cumulus clouds that move across country accompanied by much lightning but very little rain.

Courtesy Pan American World Airways

Reading Unit No. 11

HOW A SNOWFLAKE IS MADE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

In which regions of the world does snow fall? 1–251

How do snow, sleet, and hail differ from one another? 1–251-52

What is meant by a blizzard? 1–252-54

What is the usual shape of snow crystals? 1–252

Where does a snowflake go when it melts? 1–254

How many gallons of water fall on an acre of land during a one-inch fall of rain? 1–254

Where are deserts to be found? 1–256

Where does rain go? 1 256

Things to Think About

How does life depend upon snow?

How is snow used to grow crops in dry regions?

How is snow put to work?

What is the cause of deserts?

Picture Hunt

How far south does snow fall in the Northern Hemisphere? 1–256

How is rainfall distributed over the world? 1–255

Related Material

How may the color of snow change? 2–15, 66

How do glaciers begin? 1–59

How may snow blindness be prevented? 1–439

How do people travel over snow? 14–520-23

Which are some famous snow-capped mountains? 1–207, 5–443, 452-53, 462

Which birds are winter residents in your locality? 4–124-30, 223-30

What is the animal life of the Arctic? 2–329, 4–305, 312, 320-22, 411

How does plant life adapt itself to very cold regions? 13–429

Leisure-time Activities

PROJECT NO. 1: During the next snowstorm, collect some crystal snowflakes and study them under a cold microscope, 1–252-53.

PROJECT NO. 2: Make a map of the rainfall distribution of the different continents, 1–255.

Summary Statement

Snow is formed by the condensation of the moisture in the air at a temperature below the freezing point of water.

Photo by Div. of State Publicity, N.Y. State Dept. of Commerce

Learn to take cold weather as a game and then you won't fear it. If you walk briskly and take deep breaths you will love winter's frosty tingle, and his tweaks at your ears and nose will seem to be only in sport. If your hands get cold on a tramp or a sleigh ride, try carrying hot potatoes in your pockets.

HOW *a* SNOWFLAKE IS MADE

Each Little Bit of the World's Wintry Blanket Is a Thing of Amazing Beauty

THERE are millions of people who have never seen a snowflake. They never dashed down a hillside on a smooth-running sled. They never skimmed along over the frozen surface of a pond and listened to the ringing of their skates at each long stroke. For them it is always summer time. For though at certain seasons of the year clouds may swim across their skies every day and bring them rain, those clouds can never send down snow, except to high mountain tops. The exquisite, feathery stuff that gives us such a thrill whenever it starts to fall and clothe the world with beauty can usually be seen only in regions well north or south from the Equator.

For snow is formed when the moisture in the air condenses at a point below freezing and falls through layers of air that are too cold to melt it. If moisture freezes after it has been condensed into rain, it reaches us in the shape of tiny pellets that we know as sleet. They are little frozen raindrops, and must not be taken for hail, which is something quite different. If rain freezes after it falls, we have an "ice storm." Then

sidewalks, buildings, trees are sheathed in ice that sparkles in the sun like countless jewels. The world is turned to fairyland, but great is the damage that may result.

There is nothing in nature more beautiful than snowflakes—those flowers of winter that perish so quickly under a breath of warm air. Most of the ones that we see have had their delicate crystals tangled and broken in the long journey to earth. But when the air is still and the temperature is not over 25° F., one may have the good luck to gather a whole bouquet of the exquisite, glistening blossoms.

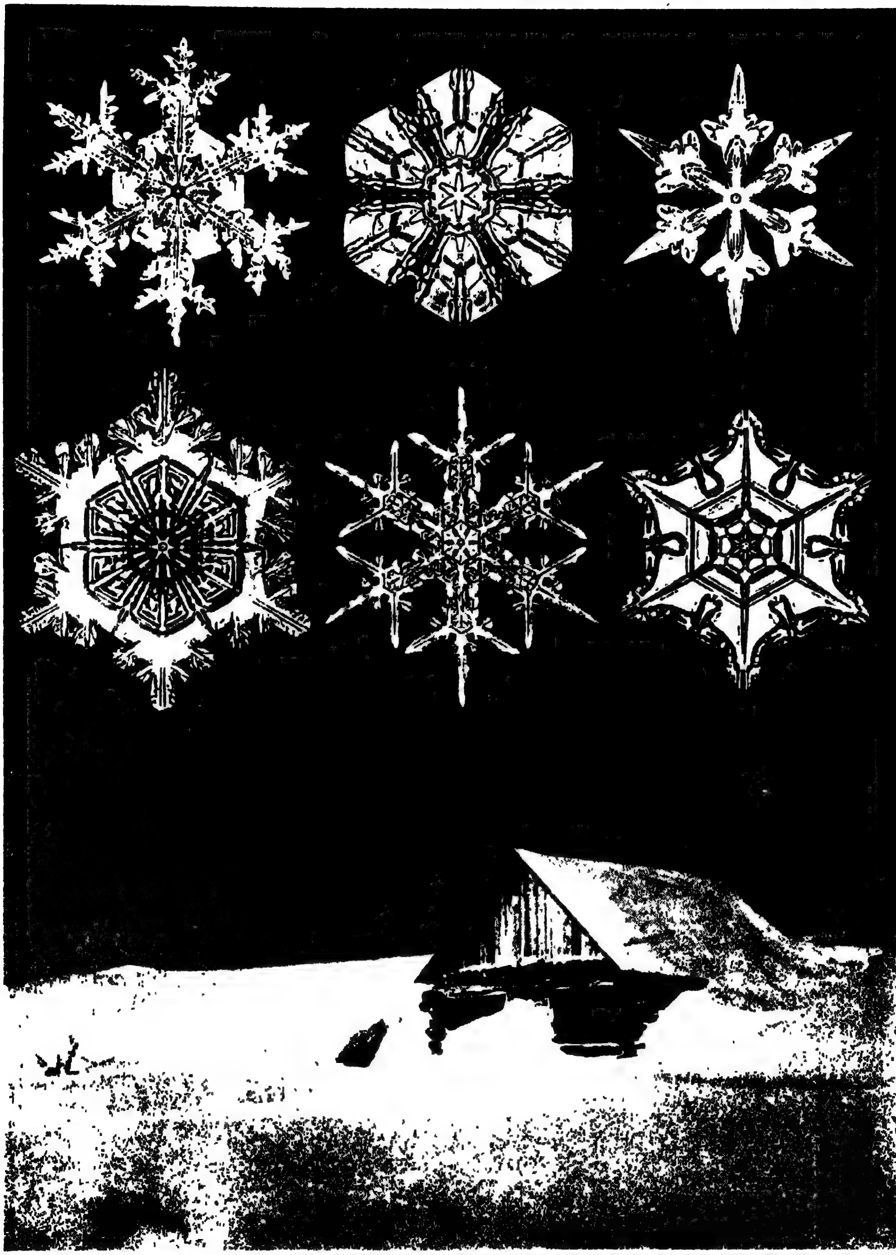
It seems a long way from those snow-clad mountain tops to the thriving field in the lowest picture. And yet it is the snows that make the fields possible in many parts of the southwestern United States. For during the winter moisture is put up "in cold storage" in the form of ice and snow on the tops of mountains. Then as the snows melt through the spring and summer, their water is drained into great reservoirs, like the one in the center, and carried by a network of canals through the neighboring deserts, which forthwith "blossom as the rose."

Photos by C. M. & St. P. Ry., U. S. Dept. of Agricult , and Sacramento C. of C.

There is literally no end to their variety. Every one of the countless billions that fall is different from all the rest—and all are alike beautiful. Under a microscope—which must be thoroughly chilled if a flake is to be examined for any length of time—they show still more amazing loveliness. But no matter how great their variety, any given flake is always six-parted and perfectly regular in form. It is the countless millions of such delicate crystals that make up a snowstorm, which poets and painters have often tried to describe.

It is hard to believe that the tender flakes falling so softly on a hushed winter's day can turn into the sharp, stinging weapons with which a blizzard assails us. The gale drives them, like so many needles, into our tingling faces. It whips them up from the ground like powder and smothers us in the whirl. It heaps them in treacherous drifts across railways and streets and sifts them through every cranny and chink that it can squeeze its fingers into. Buffeted by its smothering blows and blinded in the cloud of swirling atoms, people may lose their way and freeze to death when only a little distance from home

And yet to this dreaded storm, so exciting while it lasts and so irksome when it is over, the Weather Bureau does not even give a name. "Snow with wind" is all they call it—and leave it to you and me to use the more vivid term of "blizzard." Luckily,



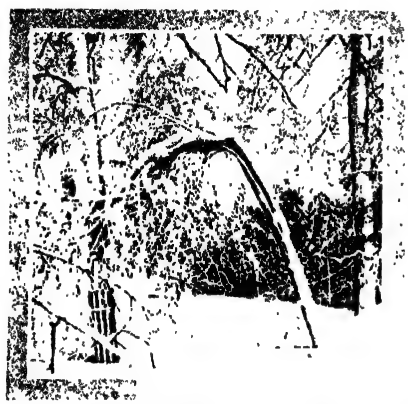
Photos by American Museum of Natural History and Bentley

It is hard to believe that all this blanket of snow is made of countless tiny flakes as delicate as the half dozen shown here, and very much smaller. No jeweler ever designed a thing more exquisite than these little crystals. Every one of them is always different from all the rest, though they all are made on the same six-parted plan. Only try for yourself to design a few, and you will realize how ingenious Nature is. It is safe to say that in all these millions of years she has never made two snowflakes just alike.

we do not have many of them to bury our walks in snow, tie up our city streets, and imprison railway trains for two or three days at a time.

How Life Depends on Rain and Snow

And yet even the blizzard may be a godsend and in the long run help save many lives. For it is the snow of the winter, deep-piled on mountain and upland, that sinks into the soil in spring and feeds brooks and rivers without which large sections of the country would be dry as a bone when summer comes around. In many parts of the western United States lands that would otherwise be desert rely on the winter's supply of snow for irrigation in summer.



Photos by American Museum of Natural Hist.

This is what happens when Goat Island, at Niagara Falls, is turned into fairyland.

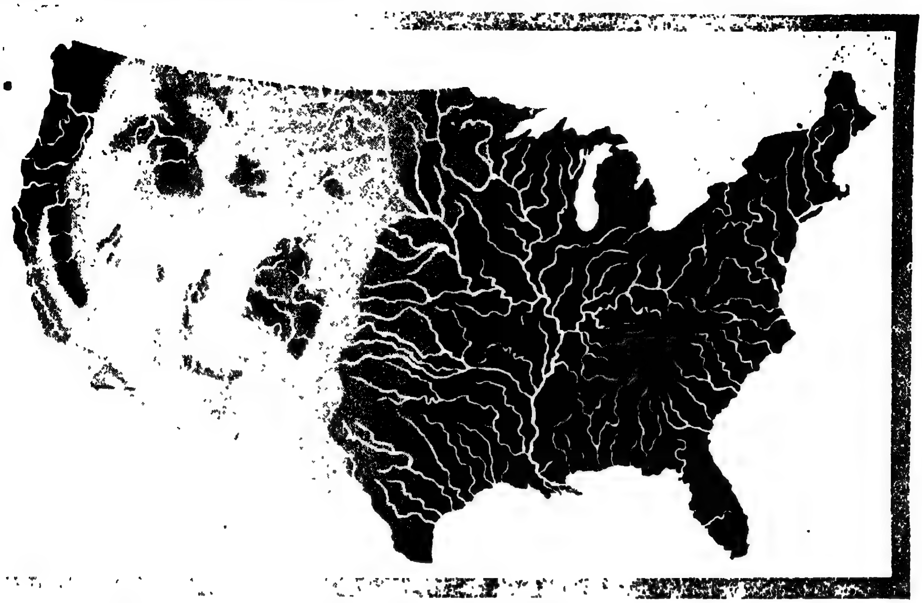
In fact, if it were not for rain and snow—what the weather man calls "precipitation" (prē-sĭp′ĭ-tā′shŭn)—all the land in the world would be a desert, and mankind could never have been born. For it is from the great oceans—that cover nearly four-fifths of the globe—that all our moisture comes in the beginning. The winds are merely the carriers—and clouds but the blanket in which the rain is temporarily wrapped.

In nearly all parts of the United States enough moisture falls to raise crops. Of course the amount varies, and not all crops are equally thirsty—though every crop must have water at certain times when it needs it most. Some plants have an enormous appetite for moisture. The roots of a single corn plant will draw several pounds of water from the soil during a warm day. Some of it goes toward building the plant, and some evaporates from the leaves and is taken into the air as water vapor. Of course a skillful farmer is careful to put in only such crops as are sure to have plenty of water.

Along the Atlantic coast and the Gulf about forty-four inches of water fall in a year, and in the northern Mississippi Valley about thirty inches. For rainfall is measured by the depth of the water it leaves. There is a container for measuring it in every weather station. A summer shower may leave an inch of water behind it. A single inch of water means that more than 166,530 gallons have fallen on one acre, and 106,680,215 gallons—or 426,720 tons—on a square mile. Imagine the extra weight on the earth after a day of heavy rain. But this is nothing in comparison with the weight of rain that may fall in a year in parts of India and the Hawaiian Islands. About a hundred miles from Calcutta is one of the rainiest spots in the world. It is deluged with six hundred inches of water a year—and sometimes as much as forty inches in a day.

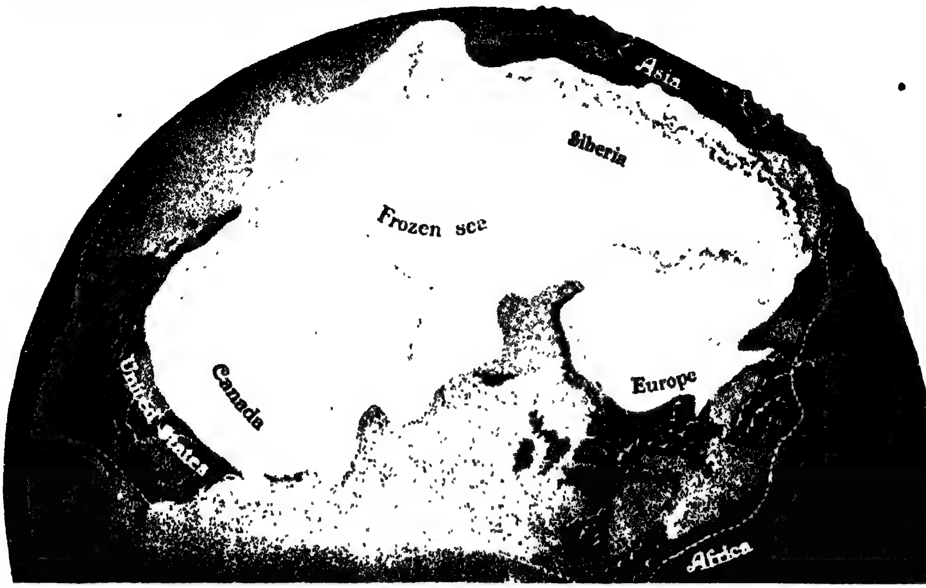
It is only in the southwestern highlands that the United States has too little rainfall to keep crops alive. Some of the deserts in Arizona have so little that it cannot be measured. But man has learned to outwit Nature. By means of rivers and canals he carefully guides the water from melting snows in the mountains and spreads it through his fields in a network of little ditches. We call the process irrigation (ĭr′ĭ-gā′shŭn). The Imperial Valley in California, one of the hottest and driest places in the world, has been changed in this way into a fertile garden.

In the Tropics rain falls only in certain



The upper map shows the distribution of rainfall over the United States. Very dark patches indicate that a given region has an extremely heavy rainfall, and light patches show a light rainfall. The Pacific coast is very moist, for the prevailing westerly winds come off the ocean laden with moisture and are forced to climb the mountains. So they drop their moisture at once, and have little left for the lands inland.

This map shows the distribution of rainfall over the whole world—the lighter the shading, the lighter the rainfall. In general, the countries whose civilization is well advanced have a good supply of rain. They are backward only if their climate is too hot. Notice that along the Equator the rainfall is very heavy, but that in general it is light farther north except where winds bring it in from the ocean.



When we speak of the "rainfall" of a region we refer to rain and snow and hail and sleet and all the other forms that moisture may take as it comes to us out of the air. But when we speak of "snowfall," we mean only snow. The map above will show you how far south snow falls in the Northern Hemisphere. The lighter the shading of an area, the heavier are its snows. Deserts, of course, get neither snow nor rain.

seasons of the year. The rest of the time the thirsty earth has to get along on water stored up in rivers or springs. The season that brings the rains is the one when the sun in its march north and south carries with it the strong updraft that always lies directly under it—the "doldrums" of the sailors. Along that belt the rain falls every day, but north and south of it the skies are usually fair, for the trade winds have little to chill them in their trip toward the Equator. The calms of Cancer and Capricorn, north and south of the trade winds, are always sparkling clear, for they are the result of a downdraft of the winds that rose over the Equator and lost their moisture in rising.

Where to Find a Desert

A glance at the map will show you that all the great desert regions, where the soil is parching for water, lie in those belts on the earth's surface that are too far from the Equator to be reached by the "doldrums" in their yearly journey north and south and too far from the Poles to get any of the rain distributed by the prevailing westerlies. The bright sun of the "horse latitudes" and of the edge of the trade winds always shines upon the great deserts of the world.

Does It Ever Rain on a Desert?

Often, too, a desert lies behind a range of mountains that dries out the prevailing winds. When a moist wind climbs a mountain, it is chilled by being forced up and drops its moisture on the windward side. So when it sweeps down the other side it is warm and dry and cannot bring rain. That is what happens to winds coming in from the Pacific and striking the Rocky Mountains. They drop their precious water on the western slopes, and many of the lands on the other side have to stay parched. Most deserts of the world do have a very slight rainfall, but some get never a drop.

About a third of the moisture that falls from the skies sinks into the earth, another third is taken up into the air again as water vapor, and the rest runs off into streams and rivers. A glance at the map will help one to realize what an enormous quantity of water flows into the Mississippi River.

Reading Unit No. 12

HOW WE WEIGH THE AIR

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the weight of all the air on the earth? 1-259
How great is the pressure of the air upon the earth? 1-259
What is a barometer? 1-259-60
How far up does the air extend? 1-260
How does the aneroid barometer measure air pressure? 1-261
What is the source of cold weather? 1-261

Things to Think About

Why can a column of mercury stay in an inverted glass tube without spilling?
What are the advantages of the aneroid barometer?
Why does air pressure decrease as one goes up a mountain?
Why does water boil at a lower temperature on top of a mountain?

Picture Hunt

How much does the air above a person's head weigh? 1-260
How are atmospheric conditions at high altitudes studied? 1-259

Related Material

How did Otto von Guericke demonstrate atmospheric pressure? 1-452-53
How is atmospheric pressure put to work? 1-458-65
How do changes in atmospheric pressure affect the ear drum? 2-304
How does air pressure help to operate pumps? 1-464-65
How does the Weather Bureau make up the weather map? 1-276, 277

Practical Applications

How can a barometer be used to measure the altitude of a mountain? 1-259-61
How is the barometer used in forecasting the weather? 1-259-61

Leisure-time Activities

PROJECT NO. 1: Climb a hill and note the changes in barometric reading as you ascend and descend, 1-258-61.
PROJECT NO. 2: Record the changes in air pressure as they are reported in the newspapers over a long period of time to see the connection between air pressure and weather. 1-259-61.

Summary Statement

Because of its weight, the ocean of air exerts a pressure of about 15 pounds on every square inch of area at sea level.

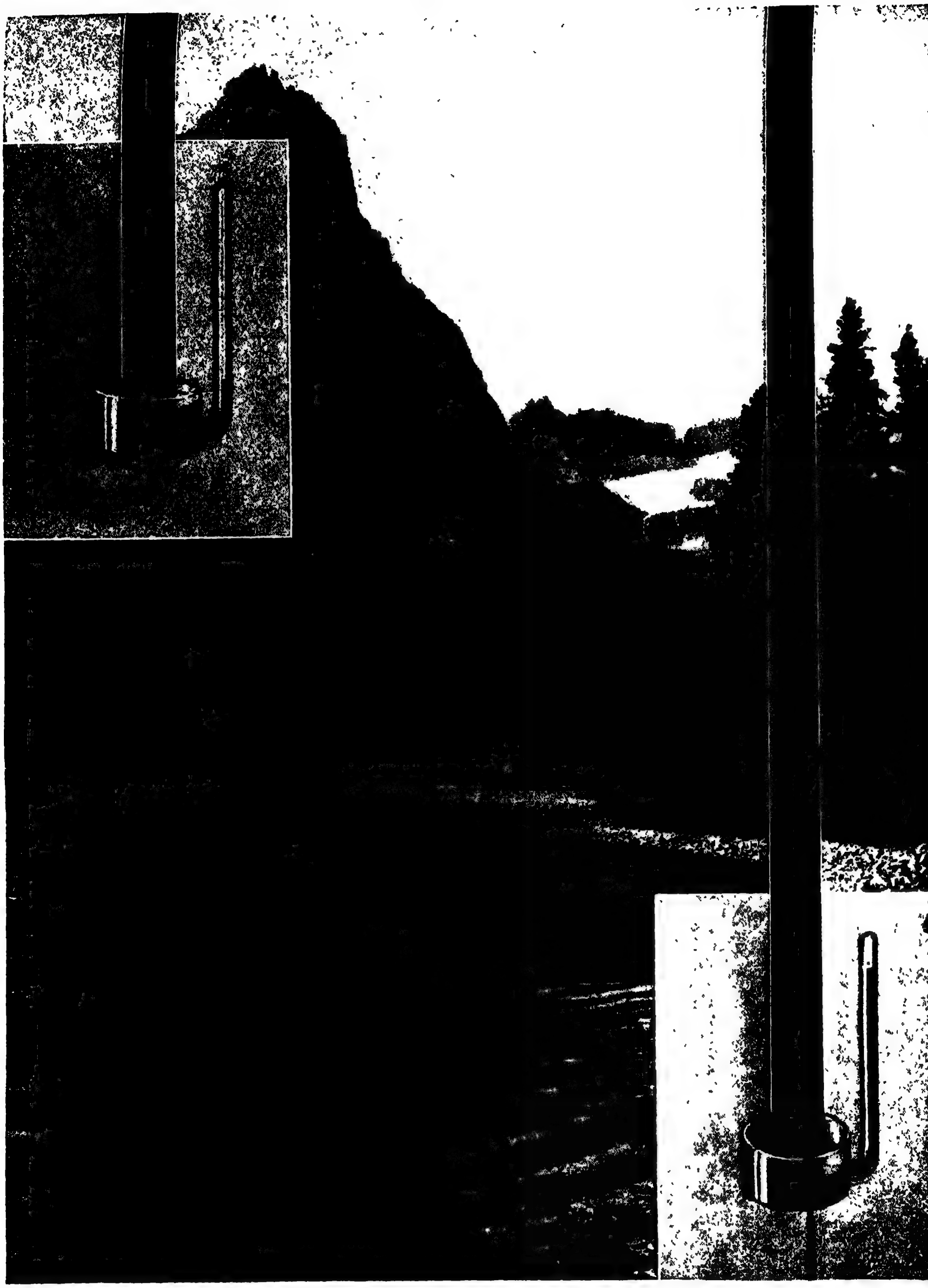


Photo from Glacier National Park

Here are two barometers, the left-hand one on a mountain top and the other at sea level. If we could see the air, we should realize that on every square inch of surface it is bearing down with a surprising weight, like a long shaft reaching right up to the top of the atmosphere. In the pictures above, we have shown two such columns of air colored black, so that you may realize just how it is that the air has weight. Of course the shaft reaching down to sea level weighs more than the one that rests on the mountain. So the air on a mountain top is "thinner" than at sea level, and water boils more quickly in it.

Photos by C. M. & St. P. Ry. and U. S. Weather Bu

These balloons are about to carry instruments high up into the air to find out for the United States Weather Bureau what conditions are like in regions man has never yet been able to visit. Such balloons have ascended as high as twenty-two miles. They are made of indiarubber, as a rule, and are not quite filled with air when they leave the earth. But as they rise into the thinner upper atmosphere, where the air pressure grows lighter and lighter, they gradually expand until at last they burst. Then a little parachute, or perhaps another balloon that will not burst, carries the instruments down to earth again. No one knows where they will land; but attached to them is a tag telling what they are for and offering a reward for their return. Instructions as to packing and shipping are also given. It is pleasant to be able to say that sooner or later most of those instruments find their way back to their owners—sometimes after a long, long time, and from points as much as two hundred miles away from the starting point. The apparatus in such "sounding balloons" usually registers temperature and air pressure, and sometimes humidity.

HOW WE WEIGH *the* AIR

Here We See How a Thing That Seems to Have No Weight at All Is Still Pretty Heavy

THE soft blanket of air into which the earth is so snugly tucked weighs 5,600,000,000,000,000 tons. Perhaps you cannot even read so vast a figure. It is five quadrillion, six hundred trillion tons. And yet the air seems to weigh nothing at all!

Now this great ocean of atmosphere is not distributed evenly. Winds are constantly pushing through it, piling it up in one place and thinning it out in another. Every storm wind that blows moves millions of tons of air from one part of the earth to another. Of course such a heaping up makes the air press more heavily in certain places upon the earth beneath. It is easy to see that changes in the weight of the air must always go with stormy weather.

In order to help him guess what kind of weather is coming, the weather man weighs the air two or three times a day. If you had to do so, how do you think you would set about it? It would take you a long, long time to work out a way! Certainly it could never be done with the kind of scales the grocer uses for sugar and coffee. The weather man uses an instrument he calls a barometer (bȧ-rŏm'ė-tẽr). With it he weighs

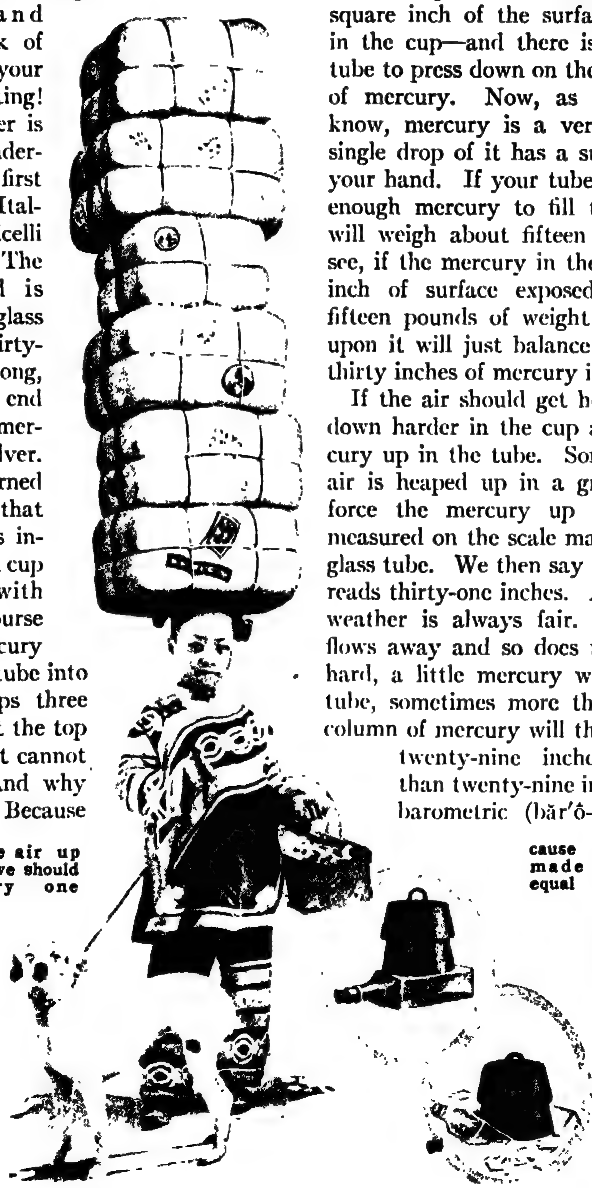
the air that rests on one square inch of earth. But what a tall column it is! It reaches out into space at least two hundred miles. And although its weight is always changing, it averages fifteen pounds. So the air that rests on a square foot—one hundred and forty-four square inches—of ground at sea level weighs a little more than two thousand pounds. Think of all the tons your body is supporting!

The barometer is very easy to understand. It was first invented by an Italian named Torricelli about 1643. The simplest kind is made from a glass tube about thirty-three inches long, closed at one end and filled with mercury, or quicksilver. The tube is turned upside down, so that the open end is inserted in a small cup partly filled with mercury. Of course some of the mercury runs out of the tube into the cup; perhaps three inches of tube at the top is empty. But it cannot all run out. And why not, you say? Because the weight of the air pressing down on the mercury in the cup will not let it. It holds the column of mercury in the tube as securely as if the tube were corked.

How We Weigh the Air

For you must remember that a weight of fifteen pounds is bearing down on every square inch of the surface of the mercury in the cup—and there is no air inside the tube to press down on the top of the column of mercury. Now, as you may perhaps know, mercury is a very heavy liquid; a single drop of it has a surprising weight in your hand. If your tube is an inch square, enough mercury to fill thirty inches of it will weigh about fifteen pounds. So, you see, if the mercury in the cup has a square inch of surface exposed to the air, the fifteen pounds of weight that the air puts upon it will just balance the weight of the thirty inches of mercury in the tube.

If the air should get heavier it will press down harder in the cup and push the mercury up in the tube. Sometimes, when the air is heaped up in a great billow, it can force the mercury up a whole inch—as measured on the scale marked alongside the glass tube. We then say that the barometer reads thirty-one inches. At such a time the weather is always fair. Then, if the air flows away and so does not press down so hard, a little mercury will run out of the tube, sometimes more than an inch. The column of mercury will then reach less than twenty-nine inches high—and less than twenty-nine inches is a very low barometric (băr′ō-mĕt′rĭk) pressure.



If we could do the air up in tight bundles, we should find that every one of us carries a weight like this on his head—for every square inch of surface has to support a weight of fifteen pounds of air. So on his whole body each one of us has to stand a pressure of some 30,000 pounds of air. How can it be that we are not crushed to jelly beneath such an enormous weight? It is because our bodies are so made that there is an equal pressure inside, to support them. We are more or less like the upper of the two bottles in the picture. The air inside has been compressed till it pushes outward with a force equal to the weight on top, so the bottle is safe. But let the air escape by taking out the cork, and the heavy weight will crush the bottle.

It means stormy weather. So, strange as it may seem, we report the weight of the air by inches instead of pounds.

A mercury barometer is the most reliable, but it is expensive and bulky to carry about; so for all ordinary purposes the aneroid (ăn′ẽr-oid) barometer is used—named from two Greek words meaning "not moist." It has no liquid of any kind, but is like a small metal box with a very thin, elastic cover. Most of the air has been drawn out from the inside of the box, so that when the pressure of air is increased on the cover, there is nothing to keep the thin sheet of metal from being pushed inward under the weight. When the pressure is lighter the cover comes back into its first position again. The slightest movement of the cover back and forth is registered by a pointer on a dial, and the figures are so gauged as to read the same as the scale in inches on a mercury barometer.

Historical Medical Mu

Toricelli is here shown experimenting with his barometer.

Because the pressure of the air can change so quickly, every station of the Weather Bureau has an attachment by which the barometer can record all its changes. A strip of ruled paper is fastened around a drum that slowly revolves by clockwork. As it turns, a pen connected with an aneroid barometer draws a line upon the paper and records all the changes in the position of the pointer on the barometer's dial.

Where Our Cold Waves Come From

Air pressure varies greatly over different parts of the earth. Wherever the air is turning in a cyclone, the pressure is low at the center of the whirl. In some places the pressure is nearly always low—as at the South Pole and in the great updraft along the Equator. In other places it is high. There are two high-pressure areas that deal out a great deal of uncomfortable weather to the United States. One of them lies in winter over British North America and pours down a series of icy cold waves over all the country east of the Rockies. Cold winds flow out from under its great billow of air in every direction.

Another "high" anchors itself in summer out in mid-Atlantic somewhere between Florida and the North African coast, but since it first makes itself known at the Bermuda weather station it is known as the "Bermuda high." Its air gets very hot under the tropical sun and picks up a great deal of water from the ocean. Consequently, when winds flow out from it over the eastern part of the United States, they can bring us the most sweltering, sticky weather of the whole summer.

So you see there probably is a good reason why on a crisp, clear day one should feel like conquering the world. Many physicians say that a high air pressure forces more blood into the interior of the body, so that the brain and all the vital organs are well supplied. But a moist, still day, when the air pressure is light and a storm is not far off, robs us of ambition. We say that the air is "heavy," meaning that it is damp and hard to breathe. But what we ought to say is that the air is light, for it is then that it weighs the least, if the barometer tells the truth. And it is in quite a different electrical condition from air that is riding in on a keen blast from the north. The change is easy to see among patients in hospitals. Certainly it is true that the Canadian "high" sends health over all the land. Next to our generous supply of sunshine, it is our best national tonic.

Reading Unit No. 13

WEATHER PROVERBS OF LONG AGO

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Why are pieces of metal usually covered with moisture before a rain? 1–264

What is the most important factor in determining weather? 1–264

What does a mackerel sky mean? 1–264

How did sailors predict the weather years ago? 1–264

What did animals teach our ancestors about the weather? 1–265

What does a rainbow indicate about the weather? 1–265-66

Why is rain important? 1–268

Things to Think About

Why is the direction of the wind important for weather prediction?

How does the weather lore of our forefathers compare with modern means of weather prediction?

Why is it important to have constantly changing weather?

How does the movement of high and low clouds in opposite directions help us to predict the weather?

Related Material

How does rainfall affect plants? 2–193

How does tropical rain affect plants? 2–196

How does dust affect rain? 1–220, 377

How are plants adapted to aquatic life? 2–199-201

How has weather influenced civilization? 1–193-97

Why are weather reports transmitted by radio to ships at sea? 1–278, 10–116, 121

Practical Applications

How do aircraft pilots use weather reports? 1–264

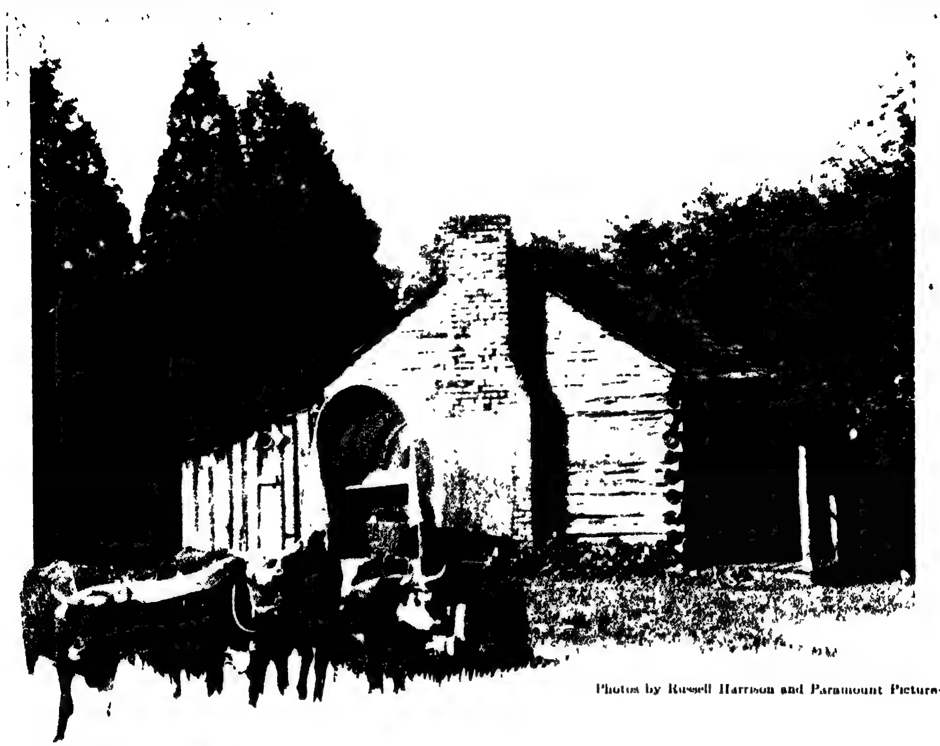
Leisure-time Activities

PROJECT NO. 1: Predict the weather on the basis of weather lore, and compare your prophecies with the predictions of the newspapers or the radio, 1–264-68.

PROJECT NO. 2: Collect some superstitions about the weather from your neighbors and compare them with actual facts.

Summary Statement

The weather lore of our forefathers contained many correct and many incorrect conclusions. To-day we depend upon the weather observers' use of scientific instruments for our knowledge of weather.



Photos by Russell Harrison and Paramount Pictures

The pioneers whose Pullman coach was a covered wagon could not set up radios in the little cabins they built, and no newspaper was left at their doors every morning. So they had to be their own weather prophets, and take their readings from the winds and clouds and other natural objects around them.

WEATHER PROVERBS *of* LONG AGO

How You and I May Become Pretty Good Weather Prophets

OUR grandparents were a good deal more clever at foretelling the weather than we are to-day. They had no weather man who pored over charts and tables and kept in constant touch by telegraph with the weather all over the country. So they learned to use their mother wit. And they were a good deal more affected by what went on in the skies than we are. A heavy rain on a pitch-black night with a rough country road ahead was quite a different thing in an open buggy or on horseback from what it is in an inclosed car with powerful headlights and a perfect roadway. So our ancestors, for thousands of years, kept a practiced eye on clouds and noted changes in the wind. And ever since the earliest man decided that he did not like the heavy stillness of a hot summer afternoon and drove the children into the cave before the storm broke, his descendants have been storing up observations on the weather and passing their experience on to their children. This is what we call folklore. Much of it was sheer nonsense; some of it was true only for the place and time when the rule was made; but a little of it is true for us to-day.

It is too bad that we do not know more about why and when the weather will change right around our homes—especially since we must always be talking about it. Many

of the forecasts from the Weather Bureau have to cover a large territory, and so cannot give much attention to any particular spot. But local forecasts are made in and for the larger cities; and the new forecasts and advices now being given for air travel go into the greatest detail for short periods. Before taking off, pilots and passengers of aircraft now know with a good deal of certainty just the kind of weather they are going to meet.

How to Be a Weather Prophet

Anyone who would know the meaning of the sky and its signs must own and study a good cloud atlas, which classifies, names, and explains clouds, just as botanies tell us how to understand and appreciate the flowers of our forests, fields, and gardens. A wet forefinger held up in the breeze is a rough and ready device, centuries old, for finding out where the wind is. But any boy or girl can make a weather vane out of a very thin piece of wood and mount it on a pin so that it will work quite as well as the one the weather man uses—and very much better than some of the rusty affairs that are continually telling untruths from the tops of towers! It is even possible to make a thermometer, a barometer, and a rain gauge; you will find directions for them all elsewhere in these books.

Weather Lore of Our Forefathers

Of course none of those instruments are necessary, but if you want to be really scientific you will set them up and take readings from them regularly, as often as three or four times a day. And the record of those readings, jotted down in a little book, will not only furnish a great deal of interesting discussion and settle many an argument as to what the weather usually has been and when the first frost comes, but it will soon teach you amazingly interesting things about how temperature and air pressure affect the weather in your particular locality. For every spot has its own weather rules, resulting from the effect of neighboring seas or mountains or lakes or plains or deserts. It is a fascinating game to try to find them out, and one which a group of friends can well carry on together, each one making and watching a different instrument.

But first of all let us see how much we can learn from our forefathers. They had a way of weaving their weather lore into homespun rhymes that were often better science than poetry. Here is one:

> Evening red and morning gray
> Sends the traveler on his way.
> Evening gray and morning red
> Brings the rain upon his head.

The same fact had been noticed long ago, for in the Bible we read, "When it is evening, ye say, It will be fair weather: for the sky is red. And in the morning, It will be foul weather to-day: for the sky is red and lowering." This is as true now as it was twenty centuries ago. For it is moisture and dust in the air that makes the sky red at sunset or sunrise. When the air is very moist in the morning, heavy clouds are likely to form when it is heated enough by the sun to start a strong updraft. Then rain will probably fall. But at night the air will be cooled somewhat and will settle instead of rising; so clouds are less likely to form.

Why Metal Sweats before a Rain

Of course increasing moisture in the air, especially in the middle of the day, is likely to bring rain. We now know that this is because, if an updraft is started, the slight chilling will cause condensation of the damp air. Early men did not know all this, but they had noticed that certain signs of increasing moisture were likely to come before a rain. So the learned Roman Pliny (plĭn'ĭ) said that when metal "sweats" it is a sign of bad weather; and the North American Indians made the gruesome observation that "when the hair grows damp in the scalp house, we surely shall have rain." The early New Englanders had the homely saying that "a red sun has water in his eye"; and people all over the world have noticed that when the salt grows suddenly damp or walls gather moisture, rain is probable.

So an elaborate apparatus has never been

Photo by Swiss Federal Rys

The shepherds who tend their flocks in the Alps have inherited a whole set of weather proverbs from their forefathers; and even to-day many of those old sayings are as useful as they were centuries ago.

necessary to tell men when the air was nearing the condensation point and would soon drop rain. Outdoor workers could see the signs all around them. The gardener noticed that the sunflower raises its head when the air grows damp and that all flowers seem to give off a stronger perfume. He thought, too, that when spiders strengthened their webs rain was to be expected, and saw that the morning-glory closes its trumpet at the approach of a shower.

Are Animals Weather Prophets?

The shepherd, anxious to save his tender lambs from the chill of a downpour, had a wealth of "signs" at his command. His sheep frisked about before a rain, for they were glad of the change from dry air to a comfortable moisture. Horses and cattle grew restless. Fowls oiled their feathers and were unusually noisy. And so sure were the bees to stay close to the hive that they gave rise to the saying, "A bee was never caught in a shower." If he looked skyward the watchful shepherd saw that certain trees—the sugar maple, the cottonwood, and the sycamore—showed the under sides of their leaves if wet weather was on the way.

What the Rainbow Tells Us

One of the most famous of all the weather prophecies for shepherds is the old rhyme:

Rainbow in the morning,
Shepherds take warning;
Rainbow at night,
Shepherds delight.

And it may often prove true. For since most storms come from the west and since, in order to see a rainbow, you must be looking into raindrops with the sun behind you, it naturally follows that if it is the morning light that is being reflected by the

rain, the storm must be coming up in the west. But if you are seeing your rainbow in the evening, with the sun behind you, the shower must be vanishing eastward.

Men Who Went Down to the Sea

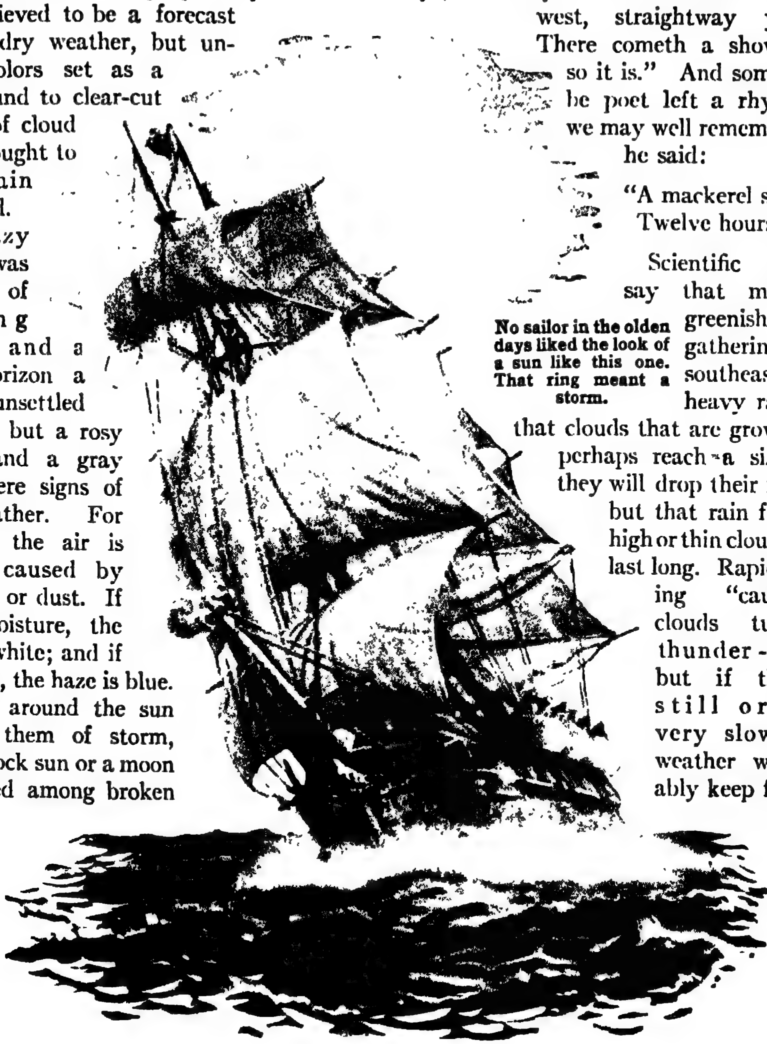
Sailors, whose very lives depended upon their skill in forecasting weather, used to watch the sky with great anxiety. They, too, would notice all the signs of increasing moisture. So they learned that a whitish-yellow western sky meant rain, and that a white, yellow, or greenish-yellow sunset meant a storm. A purple sky overhead they believed to be a forecast of hot, dry weather, but unusual colors set as a background to clear-cut masses of cloud were thought to bring rain and wind.

A hazy sunset was a sign of coming storm, and a hazy horizon a sign of unsettled weather; but a rosy sunset and a gray dawn were signs of fine weather. For haze in the air is always caused by moisture or dust. If it is moisture, the haze is white; and if it is dust, the haze is blue. A circle around the sun warned them of storm, and a mock sun or a moon rising red among broken clouds meant rain. There was also a saying that "the moon with a circle brings water in her beak"—and the larger the moon's halo, the sooner rain was expected. Pliny left us the observation that before a rising wind the fainter stars cannot be seen, even on a clear night. We know to-day that this is because churning air currents up above disturb the light rays. A few stars twinkling brightly against a very dark sky also mean rain—for moisture dims the fainter stars.

Of course clouds are one of the best weather prophets, even for the scientist. The Bible says, "When ye see a cloud rise out of the west, straightway ye say: There cometh a shower; and so it is." And some would-be poet left a rhyme that we may well remember when he said:

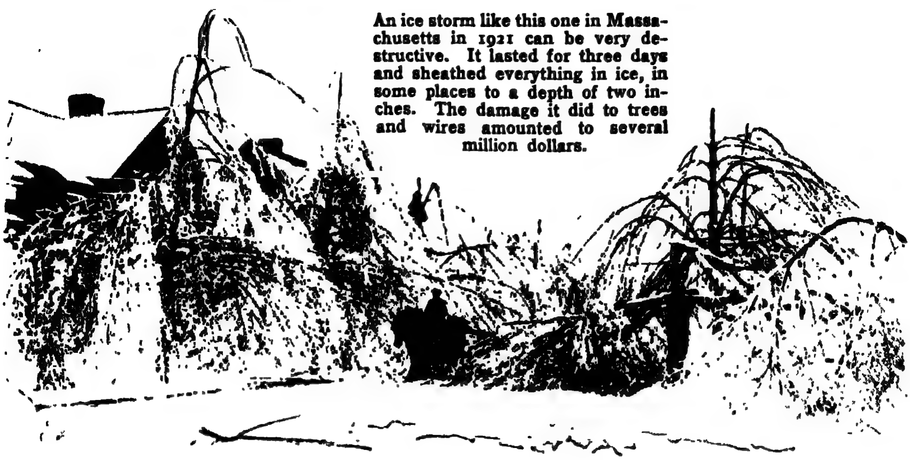
"A mackerel sky—
Twelve hours dry."

Scientific prophets say that masses of greenish cloud gathering in the southeast mean heavy rains, and that clouds that are growing may perhaps reach a size where they will drop their moisture; but that rain from very high or thin clouds cannot last long. Rapidly growing "cauliflower" clouds turn into thunder-heads, but if they are still or move very slowly, the weather will probably keep fair. If a



No sailor in the olden days liked the look of a sun like this one. That ring meant a storm.

Photo by the Knapp Company



An ice storm like this one in Massachusetts in 1921 can be very destructive. It lasted for three days and sheathed everything in ice, in some places to a depth of two inches. The damage it did to trees and wires amounted to several million dollars.

Photo by U S Weather Bureau

layer of cloud against the side of a mountain range rises, the air pressure is rising also: if it drops, the air pressure is falling.

Wisps of cloud in a white sky show the approach of an area of low pressure with rains—though sometimes the center of the storm may be as much as a hundred miles away. After the storm center has passed, the same clouds appear. If high clouds cover the sky there will be no rain unless they sink to lower levels. If they do, look out for a storm.

The Weather Carriers

Of course the direction of the wind is one of the first things that a weather prophet notices, for the great cyclones that distribute weather always carry a variety of breezes. A wind square in the east means, as a rule, that the center of the disturbance will pass near or to the southward. Rain then is almost certain. In general, winds that blow from the west, northwest, or southwest bring fair weather over the eastern part of the United States, though along the Pacific coast and the coast of Western Europe the west wind, loaded with moisture from its journey across the ocean, brings bountiful rains.

Veering winds should be watched with interest, but after a long spell of wet weather a change of the wind to the west or north will probably blow the clouds away. The reason for all this will not be hard to understand if you will look at a diagram of one of those great cyclones and notice the direction in which the wind blows on its various sides as it makes its counter-clockwise revolutions. You will see then why a north or northwest wind means that the storm has passed and ushers in clear, cold weather. Whenever clouds high in the heavens are moving in a direction opposite to those near the earth, you may know that a storm center is on its way or else is taking its departure.

Now all along we have told you the signs that are more or less reliable. Most of them were based on the fact that a rapid increase in the air's moisture or the passing of a storm center was apt to bring rain. But there are many false "signs"—age-old superstitions—that are still passed on faithfully from one generation to another by people who ought to know better. One of them is the old saw about March and the lion. Another is the saying as to Candlemas, or "ground hog's day," on February 2nd; and a third is the superstition regarding St. Swithin's Day, on July 15th. The second belief grew up in the United States. The third has a long history and comes to us from the Old World. It runs thus:

St. Swithin's Day, if thou be fair
  For forty days 'twill rain nae mair
St. Swithin's Day, if thou dost rain
  For forty days it will remain.

The story goes that when St. Swithin died he laid a curse upon anyone who should disturb his grave after his death. In spite of this, his remains were moved, and by chance on that very day a frightful storm swept the land. From this accident the belief grew.

If you are interested in learning more weather proverbs, you will find many of them in Professor Edward Garriot's "Weather Folklore," published by the United States Weather Bureau.

It is a common saying that everyone complains of the weather but that no one does anything about it; and certainly it is true that people are perhaps a little sillier in their discussion of that eternal subject than they are about anything else. If it rains, they grieve because it is not fair; if it is fair, they grieve because it is too cold; if it is warm, they grieve because it is too damp; and if it is dry, they grieve because the wind blows. They seem to take it as an insult that fate should not send them the kind of weather they want every day in the year.

This pair is not going to worry because of a little rain.

Now one reason why it is so silly to be always complaining of the weather lies in the fact that no human power can change it. So to complain about it is just about as foolish as crying because you cannot go to live on the moon. The wise and successful man makes the best of things as they are, and in doing so does something better than change them—he conquers both the uncomfortable conditions and his own silliness.

To do that is much better than being able to order from the weather man the kind of day you would like to have. For if we could do that, people would always be fighting to see who should have his way. When I wanted rain to water my garden, you would want sunshine to go on a picnic, and when I wanted it warm because I like to go swimming, you would want it cold because you like to skate. Crops would often die, men would probably be ill a good deal oftener, and the world would be turned upside down. On the whole the kind of weather we get is the kind that is most likely to make our lives run smoothly. If by chance there are floods or a very long dry spell, the thing is so unusual that the papers are full of it.

So most of us would do well to stop worrying about the weather and take it as it comes. By watching the clouds and the winds and the weather reports, we can learn to forecast it for some twenty-four hours, and so keep reasonably comfortable. And people of sense never complain of what they cannot help!

Reading Unit No. 14

WHY THE SKY IS BLUE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the sky? 1 270
What causes the color of the sky at dawn? 1 270
When are the best rainbows formed? 1–271
How many colors does sunlight have? 1–271
What is meant by refraction? 1-271
About how thick is a rainbow? 1–272
What is the cause of a ring around the moon or sun? 1–272
What is a mirage? 1–272

Things to Think About

How may white light be divided into many colors?
How does the thickness of the air blanket around the earth affect the color of the sky?
How does weather affect the color of the sky?
How is a rainbow produced?

Picture Hunt

Why may a halo form around the sun or moon? 1-272
How may the colors of sunlight be examined? 1-271

Related Material

Who discovered the cause of the color of the sky? 13-390
Do our eyes see all colors equally well? 2 299
How do the different colors look when seen through variously colored glasses or in colored lights? 1 429-30
How is color used to determine the age of the stars? 1 173
How is color used to determine the composition of things? 1-187
What does the atmosphere do to light? 1 140, 175-77
What is the source of the sun's light? 1-109-18, 207, 386

Practical Applications

How is color composition determined? 1–271

Leisure-time Activities

PROJECT NO. 1: Show what refraction is by standing a pencil in a glass of water, 1 271.

PROJECT NO. 2: Produce a rainbow with the aid of a garden hose, 1-271.

Summary Statement

The sky seems blue at certain times because small dust and water particles in the air reflect only the blue light of the sun to our eyes. The other colors in the sunlight pass through the air or are reflected at such angles that they do not reach our eyes.

Photos by Niagara Falls C. of C.

Winter has a fine gift for scenic effects. Even an ugly city street is imposing under a blanket of snow; but when Niagara Falls is partly sheathed in ice, the sight is stupendous. Up in the corner is a view of the falls before the fingers of the frost got to work and built those towers and hanging colonnades.

WHY *the* SKY IS BLUE

It Is All a Trick of the Air That Carries the Sun's Rays and Spreads Them Out in Space

HOW would you describe the clear blue sky to a man who had never seen it? A shining dome? Perhaps. But you cannot see it curve.

A blue bowl upside down? But that, too, gives a shape to something that is really not round at all.

And what should you say it was made of? Marble, glass, velvet? Surely not! All those substances look much too hard.

The truth is that there is nothing else in nature that looks just like the heavens on a clear summer's day—and that is because there is no other place where we can look on and on into vast oceans of empty space.

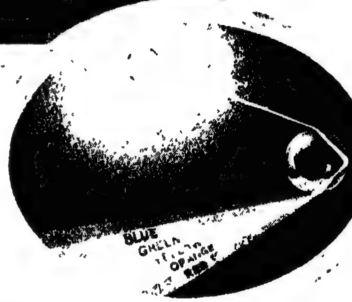
And yet it is not really empty, for if it were, we should see nothing but inky black stabbed with bright points of light—the sun and moon and little twinkling stars. That is what the airman sees when he climbs six or seven miles above the earth. What we are really looking at is countless invisible particles of moisture and dust and still tinier atoms of gas. Those are what make up the air—and it is the air that looks blue. For all those tiny atoms sift and hold blue rays out of the sunlight and scatter the sunbeams about until, no matter where we look, the world seems bathed in light. And when, at sunset, the rays of light have to pass through a still greater thickness of air, the orange and red and yellow ones are caught by the tiny particles and pinned to the western sky.

It is the air, then, that we can thank for our beautiful blue heavens and our gorgeous skies at sunset; and since this is true, you can readily see that the weather will have a great deal to do with the color of the sky. No one can mistake the promise of a clear blue sky; and the color of the west at evening often tells us quite plainly

what the weather will be next day. A practiced eye can read all such signs.

What Makes the Rainbow?

But the air gives us a great many beautiful effects besides blue skies and sunsets. Do you remember the joy of Noah when, after the long, dark weeks of rain and the terrors of the Flood, he saw a rainbow in the sky, and took it for a promise that mankind would never be destroyed in that way again? Something of Noah's thrill of delight we feel, even to-day, at sight of the exquisite bow that comes after a storm.



Of course our pencil isn't really broken. It is only that the water has bent the rays of light passing through it, and so the part of the pencil that is under water seems to be out of place. Glass, too, will bend a ray of light. And since sunlight is made up of rays of many colors, all those colors may be sorted out by passing them through a glass prism, like the one in the center, which spreads them out in a rainbow. The reason for the sorting is that each color is bent at a different angle from all the other colors. A drop of water acts in just the way a prism does. It sorts a ray of light into the colors that make it up and spreads them out in a rainbow. So when we get millions of drops of water up in the sky, all at work at once sorting out the colors in the sunlight, we have a beautiful rainbow as the result.

But everything must be just right if we are to see it. The sun must be shining in one part of the sky while the rain is still falling in another, and we must stand with our backs to the sun and have the rain in front of us. Then, if everything is right, we shall see almost a half circle of color in the sky above us. Now and then a second bow will show faintly outside the first, and sometimes, but very rarely, even a third—between us and the sun. Red is the outside color in the brightest—or primary (prī′mȧ-rĭ)—bow, and the inside color in the secondary bow. The rainbow is seen best when the sun is about halfway down the sky to the horizon.

How to Make a Rainbow

But you can make your own rainbow. By standing with your back to the sun and throwing a fine spray of water into the air from a garden hose, you can sometimes create a full circle of color. This little rainbow is just as real as the big one up in the sky, for it is made in just the same way.

When a ray of light passes from one substance into another, it is likely to be bent out of its course. That bending we call "refraction" (rē-frăk′shŭn)—from the Latin for "break up." It is refraction that makes a stick look broken when you thrust it slantingly into water. The light rays are bent as they enter the water.

Now a beam of sunlight, you may remember, though it looks white, is really made up of all the colors of the rainbow; and when it passes from one substance to another—as from air to water or from air to glass—those colors are bent and all sorted out, one from another, and spread out before us in a many-colored band of light. The rainbow, then, is caused by refraction. For all the millions of drops in a shower bend the rays of the sunbeams, sort out the various colors, and array them in the sky before us.

Where Is the End of the Rainbow?

But as for the crock of gold that the old story says is at the foot of the rainbow—it is as far away as all other bright things that seem beautiful because they are just out of reach. For it is in the nature of things that the foot of the rainbow can never be arrived at. It is always just a few rods in front of you, and moves away just exactly as fast as you walk toward it. So there are really just as many different rainbows as there are persons looking at them, and

whenever you move you see a different rainbow—which is only to say that a different set of raindrops is refracting the light that you see. The rainbow is only as thick as the little drops that are causing it—and no matter how near it may be, it is always just out of reach.

Once in a while you will see a ring of light around the sun or the moon. It happens when you look through very high, thin clouds—cirrus (sĭr′ŭs) clouds—composed of ice crystals that bend the rays of light. This small, faint ring around the sun or moon—but at some distance from it—is called a halo (hā′lō). Its inner border is brownish red. There is a very old saying—of no real value—that the number of stars you can see inside the ring tells you the number of days that will pass before rain will fall; but one can be sure that the weather man never wastes any time counting them! Sometimes several halos cross each other, with brighter spots where they meet. Such spots are often called "mock suns" or "sun dogs."

No accident has happened to our old friends the sun and moon in these two pictures. It is only that we are looking at them through very high, thin clouds made up of ice crystals that bend the rays of light. The result is that, like the saints in pictures, both sun and moon seem to be wearing a halo.

The broad whitish disk that you sometimes see showing next the sun or moon is called a corona (kô-rō′nȧ)—or "crown." It is caused by thin, misty lower clouds made up of very tiny water droplets, which scatter the light and so cause the "crown." Now these are the commonest tricks the air can play, but there are others seen occasionally. There are the strange mirages (mê-räzh′) that appear at sea or over deserts and deceive weary sailors and travelers with what seem to be castles and ships and trees. They are caused by the bending of light rays that pass through layers of air heated to widely differing temperatures; the rays are "refracted" just as they are in passing through water. You may see much the same sort of thing taking place in the air just above a paved road as you motor along it on a hot summer day; the road will often seem to be covered with water, or even with growing grass.

Reading Unit
No. 15

WHAT THE WEATHER MAN DOES

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How long has the Weather Bureau been in operation? 1–275-76

How accurate are the Weather Bureau's forecasts? 1–275

How many people record the weather daily? 1–276

How are weather observations recorded automatically? 1–276

What are "highs" and "lows" on a weather map? 1–277

How may a person help the Weather Bureau? 1–278-B

Things to Think About

How do "lows" usually move across the United States?

How do farmers make use of weather reports?

What is the purpose of each instrument for measuring the weather?

How are people warned against storms and floods by the Weather Bureau?

Picture Hunt

Describe the instruments used to study the changing weather? 1–274

How is the wind at high altitudes observed? 1–278

Related Material

How does the Weather Bureau help ships at sea? 1–277

How are valuable crops saved with the aid of weather reports? 1–277-78

What are some superstitions people hold about the weather? 1–263-68

How is atmospheric pressure related to weather forecasting? 1–259-61

How may weather be forecast from studies made of the sun's light and heat? 1–266

Practical Applications

How often do aviators in flight receive weather reports? 1–278

What necessary weather information does a ship captain receive before he sets sail? 1–278

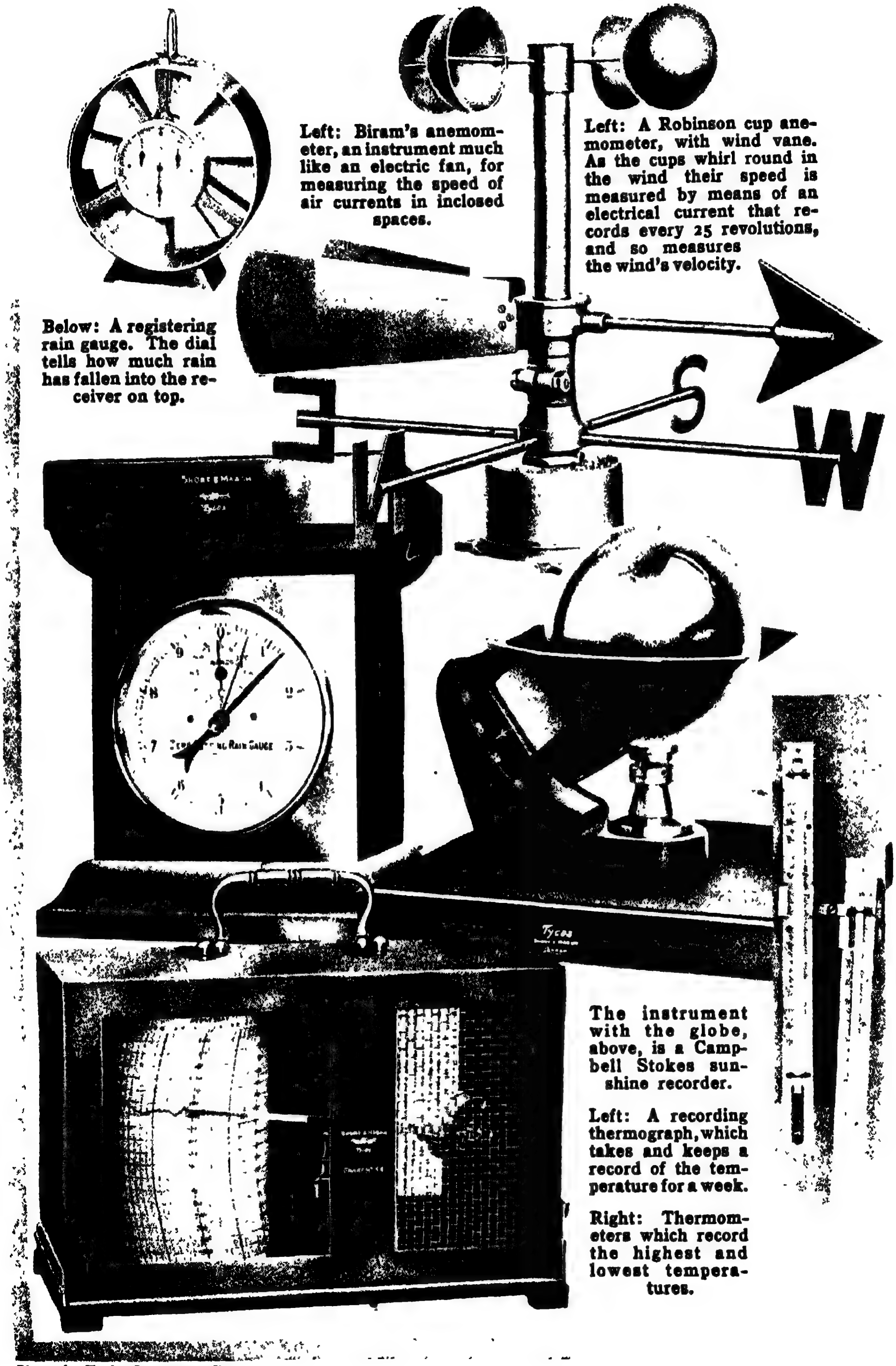
Leisure-time Activities

PROJECT NO. 1: Make a wind gauge and a weather vane, 14–48.

PROJECT NO. 2: Make a barometer and a rain gauge, 14–48.

Summary Statement

The Weather Bureau issues daily weather reports and weather maps made up on the basis of hundreds of readings of scientific instruments located in hundreds of different stations in the United States.



Left: Biram's anemometer, an instrument much like an electric fan, for measuring the speed of air currents in inclosed spaces.

Left: A Robinson cup anemometer, with wind vane. As the cups whirl round in the wind their speed is measured by means of an electrical current that records every 25 revolutions, and so measures the wind's velocity.

Below: A registering rain gauge. The dial tells how much rain has fallen into the receiver on top.

The instrument with the globe, above, is a Campbell Stokes sunshine recorder.

Left: A recording thermograph, which takes and keeps a record of the temperature for a week.

Right: Thermometers which record the highest and lowest temperatures.

Photos by Taylor Instrument C[illegible]

Photo by U S Weather Bureau

These animals had no ark in which they could take refuge during the Mississippi flood of 1927, but they found this mound to take refuge on, and seem to be contented. Their owners and other people in the flooded area received valuable help from the United States Weather Bureau during the disaster.

WHAT *the* WEATHER MAN DOES

A Great Force of Trained Scientists Is Always at Work to Tell Us Whether It Is Going to Rain or Snow, Melt or Freeze

YOU and I can squint knowingly at the west, look at the weather vane and sniff the air for moisture, and, then if the sage prediction we bring forth proves to be altogether wrong we can conveniently forget it and go on about our business. But the weather man must take more pains. He must spend all his time studying the weather's whims; and he cannot prophesy so light-heartedly as you or I. The record of all his forecasts is kept carefully and his mistakes are all chalked up against him. If our own prophecies go wrong, it seldom makes any difference, but often millions of dollars hang upon his prediction.

His task, too, is a very hard one. For the study of meteorology (mē′tē-ŏr-ŏl′ŏ-jĭ)—the science of the weather—is quite young, and there is a great deal still to be learned about it. The Weather Bureau is constantly finding things out, but of course such discovery is slow and painstaking work. And meanwhile people clamor so loudly to be told what the weather is to be that the scientists on the bureau have to go ahead and do the best they can, though they often are working in the dark. Even then they are right more than four times out of five—and they almost never make a really costly mistake.

It is only since the close of the Civil War that we have had a Weather Bureau. At

that time Congress voted a small sum—less than fifty thousand dollars—to make within the army signal service a weather service for all the people of the United States. General Albert F. Myer, chief signal officer of the army, was put in charge of the new bureau, which was part of the War Department and was the fourth organization of its kind to be founded in the world. From this infant, our present far-flung Weather Bureau has grown. It is now a part of the Department of Commerce.

"Old Probs"

The task of building up the bureau was not easy. Little was known then about weather science, and so often did the forecasts contain the word "probably" that it was not long till General Myer came to be known as "Old Probs." But he and his handful of helpers did excellent work. They laid the foundation for an organization that now employs nearly four thousand regular observers and forecasters and over six thousand volunteers. The weather information is gathered by the most modern means of communication, and is made public to millions who read it in the newspapers and hear it over the radio. In fact, the weather forecast is the first item that many readers look for when they open a paper. For the weather is a fascinating subject to nearly everyone.

Wonders of a Weather Station

A regular weather station is marvelously equipped to find out what is going on in the skies. There are thermometers that keep a record of each day's highest and lowest temperatures. Others record—with pen and ink—the temperature at every instant of the day; they are called "thermographs" (thûr′mô-gräf) "temperature writers." Then there are barometers (bȧ-rŏm′ê-tẽr) for measuring the weight of the air and barographs (băr′ô-gräf) for making records of its weight at every instant with pen and ink. Hygrometers (hī-grŏm′ê-tẽr) measure the moisture in the air, and rain gauges (gāj) not only keep an account of the amount of rain that has fallen during a day but also record each hundredth inch that falls during every minute of the day. Wind meters show the direction and speed of the wind, and sunshine recorders tell the number of minutes during which the sun shines each day. Balloons carry instruments high above the earth's surface to report by radio the condition of the upper air. One can hardly think of any weather fact that some knowing little instrument does not reveal and studiously write down in black and white.

Volunteer observers are provided by the bureau with thermometers and rain gauges and take their readings at home. They make a report of the highest and lowest daily temperatures, the direction of the wind, the time and amount of snow or rain, and the degree of cloudiness.

How a Weather Map Is Made

At a good many of the regular weather stations scattered over the country readings of the instruments are taken and reports made at every hour of the day and night throughout the year. These reports are telegraphed by means of a simple code to all other stations and to the Weather Bureau in Washington. Each station immediately sets down on a map the information it has received from all over the United States, the forecasts are prepared, and the newspapers and radio soon carry the reports to readers and listeners. At the New York City station some three thousand special bulletins are sent out every day to shippers, railroad offices, post offices, merchants, newspapers, educational institutions, and various public places. Intelligent people everywhere are learning to understand the weather.

Weather maps are very interesting and complete in the information they report from stations all over the country. A person with a little knowledge and imagination can tell from them what was the weather all over the United States at the time the reports were made—only a few hours earlier.

Simplified versions of those maps are published in many newspapers. On such charts stations having the same air pressure are joined by lines called isobars (ī′sô-bär)—for

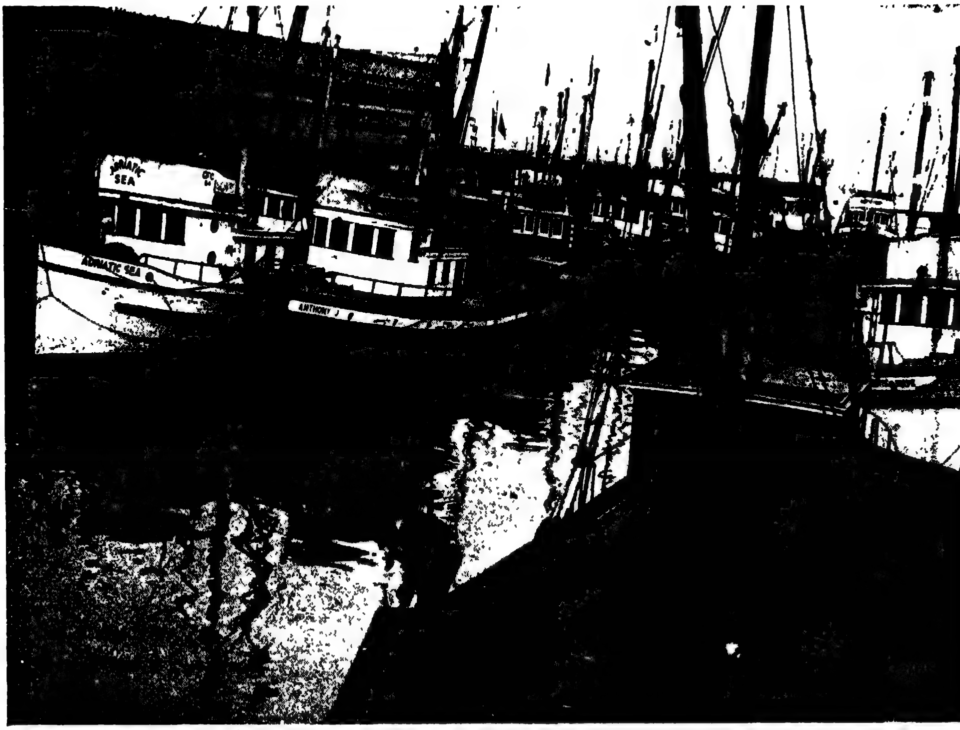


Photo courtesy Canadian Information S[illegible]

The weather bureau serves aviators, fishermen, and people in many other walks of life by giving advance knowledge of the weather. If a storm is brewing along the coast, warnings to small craft will keep these fishing boats safe in their peaceful harbor. Another signal will tell them when they can go to sea.

"isobar" means "having the same weight." Those lines form circles around places marked High, where the air has piled up into a dense mass, and also around places marked Low, where the mass of air weighs the least. A variety of different lines indicate zones—or "fronts"—where there is contact between air masses that differ in moisture, temperature, and direction of flow. Small circles of one kind or another show whether the weather was clear, cloudy, rainy, or snowy at a given station, and arrows show the direction and force of the wind.

How a Cyclone Moves

It is from such a map that the weather men in all the various stations make their forecasts. The great cyclones whose centers are marked "Low" move eastward with a fairly regular speed—usually about as fast as an express train—and four times out of five follow a regular path. It is that fifth time, when they swerve aside, that upsets the weather man's prophecies, for it is hard to tell when that is going to happen. Then, too, a great many things besides the mere progress of a storm center must be taken into account in making a forecast—tables and charts and records for other years. The weather man needs both skill and knowledge. Any single forecast is the result of care and experience on the part of a great many persons—the observers who report the conditions set down on the maps, the men who discover the general rules for deciding what the conditions mean, and the men who apply the rules to the weather of any particular day and locality. It is like a huge machine.

In Times of Flood and Hurricane

It is this machine that tells us every day what it is that the skies are probably going

to send us—and the mechanism pays for itself many times over in property saved from destruction. There are times, as in the case of floods and hurricanes, when it saves hundreds of lives. A weather man never takes chances at such a time. Whether the frost or storm is certain to come or not, he sends out the warning, for "it is better to be safe than sorry."

Watchmen of the Skies

Every year in California tons of raisins are made from grapes. After the fruit is picked it is left on the warm ground to dry—or be "sun cured." If a rain comes then the entire crop is ruined. Summer showers are very uncommon in California, but the Weather Bureau keeps close watch and if a rain threatens, it sends out warning in time for the raisins to be saved. It keeps the same close watch for frost when the orange crop is still on the trees, and for cold waves that would bring loss to shippers.

For airmen reports are sent out every hour, so that an aviator may know just what is going on in the air next the ground and at higher levels.

Whenever a vessel sails from an American port the Weather Bureau sends it the latest information as to the kind of weather it is likely to meet on the trip. Every storm that sweeps the long lanes between American and European ports is recorded daily on the weather maps and signals are sent out by wireless and telegraph to warn ships and planes in its way.

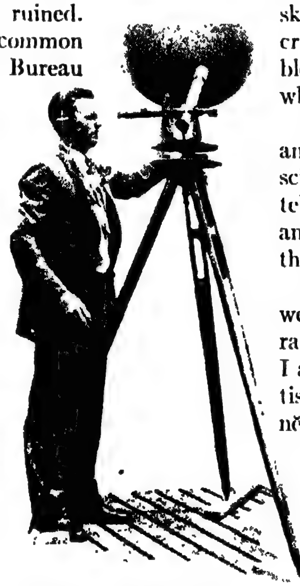


Photo by U. S. Weather Bureau

The balloon shown here is not going to carry instruments. It will be sent up and watched through a theodolite, the instrument on the tripod. By taking observations of its position each minute, the observer can measure the speed and direction of the wind at various levels.

The larger rivers are seldom flooded without a warning from the Weather Bureau to all in the way. Along the Mississippi alone many lives have been saved and millions of dollars' worth of property rescued. For farmers, too, flood and weather warnings are extremely valuable. A great deal of the work of the volunteer observers is for the purpose of gathering information that will be important to agriculture.

It is interesting and sometimes amusing that the testimony of the weather man often decides a case in court. In certain large cities such cases take a great part of the time of one of the members of the staff. No matter how often the weather man's forecasts may go wrong, his records are always correct, set down in black and white by impartial instruments and trained observers. In a famous case some time ago a witness swore that he had seen various things happen by the light of the moon, but the weather report showed that the sky was overcast the night of the crime and that no moon was visible. There was little doubt as to who was telling the truth.

All the above will show you that an army of skilled and intelligent scientists is constantly at work to tell us what the weather has been and what it is going to be within the next twenty-four hours.

Of late years the science of weather forecasting has made rapid strides. During World War I a distinguished Norwegian scientist named Jakob Bjerknes (byĕrk'-nĕs) was able to arrive at a clearer understanding of what brings changes in the weather and so could work out better ways of forecasting them. When weather reports were withheld by the countries at war he set to work to develop his air-mass-and-front theory of weather formation in order that his own people, then neutral, might have the benefit of his predictions. Some years later his system was adopted by our own Weather Bureau and now is used in preparing all our weather forecasts.

Before Professor Bjerknes made his findings public no one had understood very clearly just how a Low was formed. Professor Bjerknes showed us that stormy weather is the result of the meeting of two great masses of air that differ in moisture,

temperature, and direction of flow. The line along which they are in contact is called a "front," and it is there that Lows form and that the weather is unsettled.

There is nothing very mysterious about the formation of the Highs that swing across our country. They are merely wide areas where cold air has piled up into a vast low dome usually several hundred miles across, though only a few miles high. Such huge masses of cold air have tremendous weight, which the lighter warmer air cannot resist. They come pushing down from the frozen north—currents of cold dry air rushing over Canada, or of cold moist air flowing down from the North Pacific. Somewhere along the northern half of our country they meet masses of warm moist air pushing up from the Gulf of Mexico or of warm dry air flowing up over the southwestern deserts. The line where the warm and cold air masses meet is called a "front." If cold air is pushing warm air back, we call it a "cold front" or "polar front." But if warm air is pushing ahead into colder air we call it a "warm front."

How a Low Is Formed

Lows are formed when large masses of warm air come driving up from the south and meet cooler air that is moving with less force. The warm air current overcomes the resistance of the cooler air and advances into it in the form of a great forward curve. Like a huge wave at sea the great curve, or "warm sector," moves northeastward or eastward as the warm air is swerved to the right in its rapid advance against the colder air.

Meanwhile the wave of warm air is constantly getting taller and narrower as the heavier cold air pushes against its sides. At last a swirl is formed at the northern tip of the wave—or warm sector—and the winds begin to circle around the tip in the form of a great eddy. On the west side of the warm sector the cold air keeps on moving south. At the top of the sector the air flows in from the east. On the east side of the sector it flows up from the south or southeast. And inside the warm sector it continues to rush eastward or northeastward. The counterclockwise swirl, or "cyclone," which we have already described in our story of the winds, has now been set up, with the northernmost tip of the warm sector as its center. That point is the Low around which the winds circle.

But to complete the picture we need to realize that as the warm air advances eastward it rides rapidly up over the heavier cold air, which rests on the earth. That is to say, the warm front slants ahead and upward as it is pushed along by the weight of warm air behind it. All along the front the barometer is constantly falling. Of course the warm air is chilled as it rises. Its moisture condenses into clouds—at first high wisps, or "mares' tails," and then lower cloud masses and heavy cloud ceilings, until at last nimbus clouds are formed and moisture begins to fall. In other words, over a wide belt along the warm front—the eastern side of the warm sector—rain or snow is falling.

When a Warm Sector Brings Fog

Inside the warm sector—south of the Low—the clouds are broken or the sky may even be clear as the warm sector passes by a given spot on its eastward journey. But if the warm sector is passing over a cold area its moisture may turn to fog.

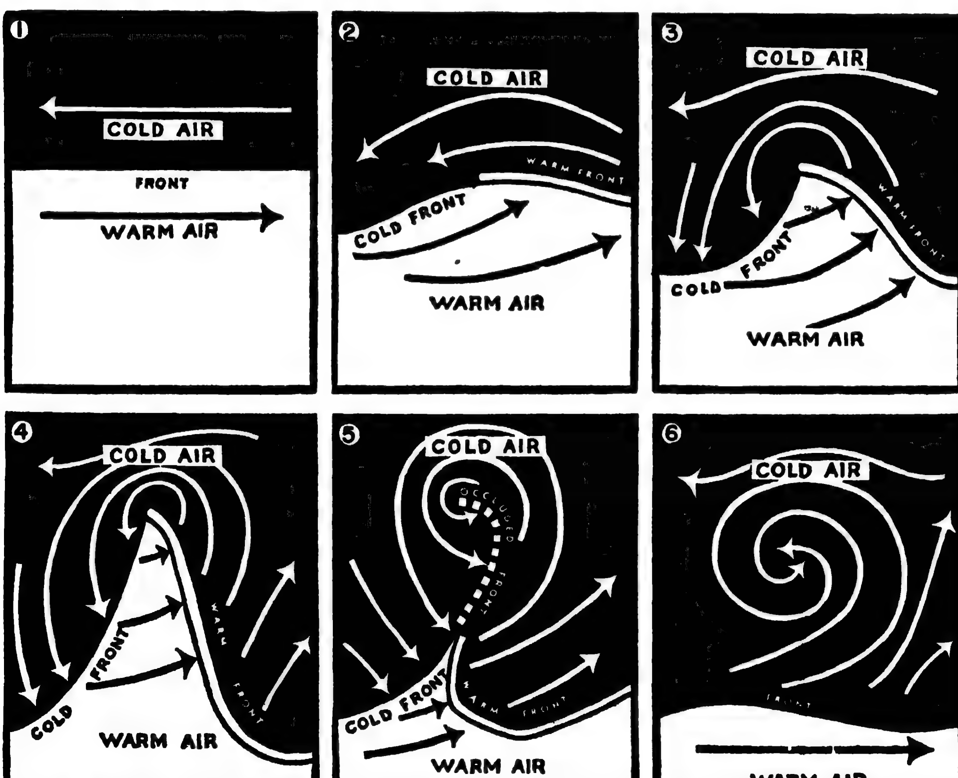
Now all the while that our warm sector is moving eastward, pushing back the cold air that lies in front of it, the cold air on the west is pushing hard behind it. And as the warm sector gets longer and narrower it offers less and less resistance to the cold air it has been displacing. The cold air, meanwhile, may perhaps have been reinforced by new masses of polar air rushing down from the north. The heavier cold air, or "cold front," pushes hard at the back of the warm sector—that is, along the warm sector's western side—and noses under it in the shape of a thin wedge of cold air that lies along the surface of the earth and pushes the warm air up. When this happens the warm air that is forced up expands and is chilled, and then condenses into clouds and falls to the earth. In other words, along the cold front there is a narrow belt where rain or snow is falling.

Usually the rain or snow along a cold front does not last long. The wind freshens. It

shifts to the north or northwest and sometimes rises to a gale. The temperature falls, the barometer rises rapidly, the clouds break away, and we have the sparkling, bracing weather that lies under a High - behind the cold front. In other words, the Low has passed and a High has come to take its place. The heavy north wind finally dies down and gentle winds circle clockwise around the high pressure area at the center of the High.

Sometimes the cold front moves eastward so fast that it overtakes the warm front. In that case the air in the warm sector is squeezed between the masses of cold air in front of and behind it, and because it is lighter it is pushed up till it rests on top of the cold air, which lies along the earth's surface in every direction. Then we have what is called an "occluded (ŏ-klōōd′) front." It is likely to bring unstable weather, for if the warm air that is high overhead contains a good deal of moisture, the moisture will condense on rising and will fall as rain or snow.

Now you have hardly read all we have had to say of the marvels of the weather without realizing that, stale as the subject may be as a topic of conversation, it is one of the most fascinating and important of sciences—though one that might be said to be in its infancy. And it is one that people quite unlearned may help to forward. Many a lonely woman on a distant farm may reach out her hand to touch the great world of science by becoming a volunteer observer working under the Weather Bureau. And she may be sure that her effort is not lost, but will go to swell the great stream of useful knowledge that men are gathering all over the world. Many a cripple, bound to a narrow circle around his home, may help to track down the roaming clouds and chart the paths of the winds.



These diagrams show how a "low"—the center of bad weather—develops, and what its life history is.

PHYSICS

Reading Unit No. 1

THE CEASELESS ROUND OF MATTER

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What do we believe to have been the origin of the sun? 1-280
When did human beings first appear on the earth? 1 281
What is an atom? 1 281
What are elements and compounds? 1 282-83
What is the "law of definite proportions." 1-283
Radium and radioactivity, 1-283
Electrons and protons, 1 283-84
Shattering the atom, 1-284

Things to Think About

How are all the sciences related?
Who are the scientists who helped discover what we know about matter?
Why is there no definite number of compounds?
What adventures may a speck of matter have?

Picture Hunt

What is the size of a salt molecule? 1-280
What laboratory equipment did the early nineteenth-century chemist have? 1-282

Related Material

How may elements be formed from compounds? 1-544-45
What is meant by the spectra c the different elements? 1 441
How do some atoms break up? 9-425
Which are the inert elements? 1-545, 547
Which elements are most active? 1-515, 547
How may X rays be used to study the digestive tract? 2 253-54
Why does molecular motion represent heat? 1-388
What is the source of an atom's energy? 1-352

Practical Applications

How has radium helped cure disease? 9-426
How did the study of matter result in the discovery of the X ray? 1-361, 419, 514, 10-492-95

Summary Statement

All matter is made up of countless tiny particles of electricity. Different kinds of electrical particles group themselves into units called atoms. Different atoms combine to make molecules.

A particle of salt so tiny that you could not taste it if it were dissolved in a glass of water contains billions of molecules. If this little particle of salt could be enlarged sufficiently for us to be able to see a single molecule in it, the salt particle would become a huge mountain, large enough to cover the city of New York. Atoms are smaller even than molecules. Electrons and protons are smaller than atoms.

The CEASELESS ROUND *of* MATTER

Our Bodies Are Made of Matter and We Live Our Lives in a World of Matter. Our Bodies Die, but Their Matter Goes on Forever. What Is This Eternal Substance from Which Everything in the World Is Made?

MORE than two billion years ago a certain star, in its swift movement through space, came close to another star. Because they pulled upon each other with great force, vast amounts of matter were drawn out from both; and when the first star passed on, the second was left smashed almost into bits. Instead of a single huge ball, it was now a swirling scattered mass of fragments, some large, some small, but all wildly revolving about what remained of the original ball.

To-day most men of science believe that the center of this seething mass became our sun, and that the larger fragments, in the course of time, became the planets. Our own planet, the earth, must, they think, have been born in this way. At any rate, no better explanation has yet been offered to account for things as they are.

If we could travel back in imagination to that early beginning, we might see a tiny speck of matter, only one of countless others, fall from space into the ball which became our earth. Other specks rained down upon it, threatening to imprison it forever; but the heat was so great that the speck melted and then boiled away into a gas. Before long, it found itself in an atmosphere surrounding the earth. A million years passed. The earth cooled. The speck of matter condensed and fell to earth again. For countless ages it lay upon the earth. Wind and water moved it now and again from place to place; but no important change occurred until life began.

How or why life began science cannot say, but soon our speck of matter became part of the living body of a tiny plant. When this plant was eaten by an animal, the speck transferred its abode to the living tissue of the animal. Later the animal met with an accident and died. The body decayed and our speck of matter was returned to the

soil. But not for long! Another plant soon drew it up, dissolved in water, and built it into the structure of its stem. When a storm snapped the stem in two and the broken plant withered into dust, a wind eventually carried our speck to the top of a mountain. Washed down by rain into a stream, it found its way to the ocean. First in the body of a small fish and later in the bodies of larger fish, the speck traveled on practically unchanged, although many living things ate it and used it, only to die and release it to some other form of life.

Adventures of a Speck of Matter

Countless ages ago there appeared on the earth the form of life which we call human beings. The same speck of matter which had lived in so many different places in ages gone by, was also found in the body of a man. This same life cell of matter became now part of a muscle, now part of an eye, was found now in the brain of one man, now in the blood of another. It played its small but important part in seeing, in hearing, in feeling, and in thinking. At times it was part of a garment worn to protect man against cold; at other times it assumed a place in the wall of a man's shelter against wind and storm. Its resting place was never permanent and always different; yet nothing could destroy it.

In our imagination we follow the adventures of our speck of matter as it lived through the conquests of Alexander the Great and the triumphs of Julius Caesar. It may have been present on the voyages of Columbus and have accompanied George Washington in his struggle for independence. One need hardly stretch one's imagination to think of this speck of matter as present in one's own body while one sits reading the pages of this book.

What Is Matter?

What is matter? What is this ageless, ceaseless, enduring thing which is all about us, out of which our bodies are made and upon which even our thoughts and acts depend? The answer is not easy to give. The most learned scientists of to-day are in doubt as to the truth about matter; for the more they learn the more baffling becomes the mystery.

More than two thousand years ago, a Greek philosopher, Democritus (dē-mŏk'rĭ-tŭs), believed and taught that the whole world was composed of space and a vast number of particles of matter. The particles were so small as to be invisible singly, and visible only when millions of them together formed an object, such as a book or a stone. He reasoned about matter in this way: Suppose you cut a stick in half; then cut one of the two resulting pieces in half; then cut one of those two resulting pieces in half. Continue this process for hours, days, weeks, until a piece is arrived at which is too small to see. Now, continue with the cutting, seeing with your "mind's eye" and using an imaginary knife. Can one keep this up forever? "No," replied Democritus, "one will finally reach a particle so small that no smaller may be had." This last particle he called an "atom," a word which in Greek means, "uncuttable."

The Four Substances of the Universe

Whether true or false, the atomic (ȧ-tŏm'-ĭk) theory of Democritus did not last. Another Greek philosopher, Empedocles (ĕm-pĕd'ō-klēz), gave rise to a different belief about matter. All substances in the universe, he thought, were made up of four different kinds of simpler substances: earth, air, fire, and water. For more than a thousand years this theory, or some variant of it, was the best idea that men could develop concerning that substance of which they and everything about them was made. Because the belief was not entirely satisfactory, the Arabian scientists added three new elements: mercury, salt, and sulphur. Mercury, they believed, made objects glisten with a metallic luster; salt made bodies dissolve; and sulphur made substances burnable.

As soon as men came to believe that one substance might be changed into another, they set about finding means for transforming less desirable matter into more desirable. If only they could change lead and iron into gold! Here was a way of becoming rich overnight. Every king and every prince

This is a chemist of the nineteenth century at work in his laboratory. His equipment was crude and his materials few; but his patience and genius gave us the first really helpful answer to the question, "What is matter?" Upon the foundations he laid, later scientists have built up a noble structure.

of the Middle Ages employed a man of science—they called him an alchemist (ăl′-kê-mĭst)—to work at discovering the great secret of transforming matter. Many of these workers were just rogues and scoundrels, who made much of the magical powers which they did not possess. But many of the alchemists were true scientists. They worked diligently and skillfully in their dirty little huts—the world's first laboratories—making discoveries and performing experiments which command the respect of scientists even to this day. Out of their efforts has grown the science of chemistry.

How Man Changes Matter

Needless to say, no alchemist ever discovered how to change lead into gold. We know now how extremely difficult a task this would be even in the most modern laboratory. Indeed, we are not at all sure that it is possible. It is certain that if we changed lead into gold by the mea..s now available, we should spend more than we gained.

That man can and *does* change matter in many ways to suit his needs is a great tribute to the scientists who came after the alchemists and who revised the old ideas and beliefs concerning the nature of matter.

It was not until the 17th century that the first great step was made in advancing our knowledge of what matter is. Robert Boyle (1627–1691), an Englishman, was the first of several men of science to discard the old idea of a few simple substances and to propose the belief that all matter may be divided into "elements" and "compounds." "An element," he said, "is a substance which cannot be split into simpler substances. If it *can* be so split up, it is a compound."

Then began a hunt for elements. Iron, silver, gold, mercury, sulphur, and many other substances were proved to be elements. Oxygen and hydrogen (hī′drô-jĕn) were discovered and also shown to be elements. This hunt has been continued to very recent times, for it is but a short while since the last two elements were found. To-day we believe that there are only ninety-two different elements found naturally in the earth. Scientists have been able to manufacture several more in the laboratory, but the total number which make up the earth is not large.

There is however, no limit to the number of compounds. New compounds are still being discovered and many are being made in laboratories every day. Yet, however new and strange a compound may be, it can be broken up into two or more of the

ninety-two elements of which everything on the earth is composed.

The next step in man's quest for knowledge about matter came with the work of John Dalton (1766–1844), an English scientist. Dalton studied carefully and closely the manner in which elements combine to form compounds. He found that in any given compound, the same elements always combine in exactly the same proportions by weight. This he called the "law of definite proportions." Dalton also revived the old Greek atomic theory and gave it new meaning. An atom, according to Dalton, was the smallest possible part of an element.

At about this time, Avogadro (a'vō-gä'-drō), an Italian scientist (1776–1856), advanced the idea of a "molecule" (mŏl'ē-kūl). This he defined as the smallest possible part of a compound which could exist and yet be that compound.

Can Matter Be Created or Destroyed?

To the ideas of Dalton and Avogadro, we must add a third idea, the product of Lavoisier (lȧ'vwȧ'zyā'), a French scientist (1743–1794). Observing the manner in which elements and compounds reacted, and weighing carefully the amounts of matter before and after reaction, Lavoisier concluded that matter cannot be created or destroyed, no matter what changes it undergoes.

The work of Boyle, Dalton, Avogadro, and Lavoisier was the first great attack upon the mystery of matter.

Not until the end of the nineteenth century did anything happen in the world of science to cast doubt upon the ideas of Dalton, or to advance those ideas in any way. The atom, as the smallest possible part of an element, and the molecule, as the smallest possible part of a compound, were accepted as the last word in human knowledge of the nature of matter. Then a startling phenomenon was brought to the attention of the scientific world, and a wonderful discovery was announced by the most brillant of women scientists. Professor Henry Becquerel (bĕk'ē-rĕl'), working in his Paris laboratory on the element uranium (û-rā'nĭ-ŭm), discovered that this substance was incessantly shooting off parts of itself—at least, something was coming out of uranium which could penetrate a sheet of metal and make an impression on a photographic plate. What was that something, and what was left of the uranium? Before an answer could be found, one of his young students, Madame Marie Curie (kü'-rē'), (1867–1934), assisted by her husband Pierre (pyĕr) Curie, (1859–1906), had found that an ore called pitchblende also behaved like uranium, but that its activity was much more powerful. Refining the pitchblende, they discovered a new element—radium.

What Radium Has Meant to Science

It is hard to tell in a few words what radium has meant to science, particularly what it has meant to our understanding of the nature of matter. Actually, it caused a revolution in the scientific world, turning many ideas topsy-turvy. It soon developed that radium—an element—was changing itself into lead. "Impossible!" you say. Yes, if we propose to hold to the belief in Dalton's atom, it would, of course, be impossible. But to be truly scientific, we must be ever ready to accept new facts and to revise our ideas to fit those new facts. So we must accept the fact that the atom is *not* the smallest possible part of an element; for does not the radium atom break up, shooting off pieces from itself? We must accept the fact, also, that some elements can be changed into others; for does not part of the radium change into lead? The old alchemists were right after all, though for reasons they never dreamed of.

What Do Atoms Contain?

It was most fortunate for science that at about the time when Madame Curie announced the discovery of radium and its strange and wonderful behavior, several other experimenters were studying the behavior of electricity when it was discharged through closed glass tubes. A striking fact appeared. The electric discharges resembled the discharges from radium. In fact, the resemblance was so close that each of the three kinds of radium discharges—for there were three kinds—could be compared with

each of three kinds of electric-tube discharges. The conclusion was plain: the radium atom was sending out streams of electric particles. Do atoms, then, contain electric particles?

Men of science, particularly Sir J. J. Thomson and Lord Rutherford, two eminent Englishmen, gave emphatic answers to the above question. "Decidedly, yes!" they said. "Not only do atoms contain electric particles but they contain both kinds of electric particles, positive and negative." To the negative electric particle was given the name "electron" (e-lĕk'trŏn); and to the positive particle, "proton" (prō'tŏn). In 1932 James Chadwick in England found that certain atoms could be made to give up particles which have no electric charge. Careful investigation, however, showed that this particle, called a "neutron" (nū'trŏn), was nothing more than a proton and electron in such close combination that their opposite electric charges canceled one another.

Photo by Soibelman Syndicate

This is Madame Curie and her daughter, Madame Irene Joliot. Madame Curie helped in the discovery of radium, which turned topsy-turvy the nineteenth century ideas as to the nature of matter. The daughter, an able scientist in her own right, is now helping, by her remarkable experiments, to clear up the mystery of matter. In all their work, both these scientists coöperated closely with their husbands, whose contributions to science are of the first importance.

Years of painstaking and ingenious experiments followed, in order to check and prove the conclusion that within the atom there were particles of electricity. And proved it was! To-day scientists are concentrating on the task of shattering the atoms of many different elements, in order to learn something about how the various particles are arranged within the atom, and to discover, if possible, just what these particles really are.

How All Sciences Are Related

In a later chapter we shall learn more about this new knowledge, but for the present it is enough to say that the mystery of matter has been solved to this extent: we can say that matter is electricity and electricity is matter!

Perhaps our reader has been wondering why we begin our story of physics with so much that is chemistry. In certain parts of this chapter we have also referred to matters belonging to astronomy, to geology, and to biology. It is because modern science has been breaking down the lines of division between the special sciences. The more we learn about one science, the more we know about the others, for they are all related. In particular, it is necessary for us to have a good understanding about the nature of matter if we are to appreciate the story of physics. Physics is above all the study of matter in motion.

When a physicist (fĭz'ĭ-sĭst) speaks of an object, a mass, or a body, he means anything which occupies space; but he understands that that which occupies space is, in the last analysis, a group of electric particles. The same is true when he speaks of matter which remains at rest unless a force acts to change that state of rest; or when he studies the many different ways in which matter may act upon matter. He always remembers that he is talking about countless billions of tiny electric particles. The hand with which he writes, the chair on which he sits, are made up of countless tiny particles of electricity. Most of us find this hard to believe. But it is a commonplace to the physicist in his laboratory, who must bear it in mind.

PHYSICS

Reading Unit
No. 2

HOW MATTER BEHAVES IN MOTION

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What goes on inside a stick lying motionless on the ground? 1–287

What does the scientist call motion in a straight line? 1–287

What are other kinds of motion? 1 287

What is the path of planets around the sun? 1–288-89

Does a planet travel in its orbit at a constant speed? 1–289-90

Will a 100-pound cannon ball and a ½-pound weight fall to the ground at the same time if dropped from the same height? 1–290

How does a clock keep time? 1-292

Things to Think About

How were moving things timed before the discovery of the pendulum?

How did Kepler work out the laws of planetary motion?

How does the work of one scientist depend upon the work of other scientists?

How can a train be made to ride on a single rail?

Picture Hunt

What makes an automobile engine work? 1–287

How does a gyroscope work? 1–291

Related Material

What is the importance of sunlight to life? 1–199, 2–321

How does the motion of the earth about the sun affect the seasons? 1–111, 201-3, 206-8

How is time used in music? 12–215

How is the calendar constructed? 10-475-83

How is the correct time transmitted to ships at sea? 10–469

How was water used to keep time? 10 461-62, 12–27

How does gravity bring water to many communities? 10–549

Practical Applications

What does the rapid expansion of molecules have to do with transportation? 1–287

How was Galileo's study of the pendulum applied to clocks? 1–287-92

Leisure-time Activities

PROJECT NO. 1: Perform various experiments with a gyroscope to show the behavior of moving bodies, 1-291.

PROJECT NO. 2: Perform Galileo's experiment with falling bodies, 1-292.

Consider the many different motions of a man walking through a moving train. He moves with respect to the train. The train moves with respect to the earth. The earth not only spins on its axis, but moves about the sun. The sun, carrying its entire family of planets, moves through space at a speed of about twelve ı a second. And that is not all, for there is every reason to believe that the whole universe of which the sun is but a single star, is itself moving through space. Three of these movements are indicated above.

HOW MATTER BEHAVES *in* MOTION

Physics Begins with a Study of Matter in Motion, and the Early Physicists Performed Great Feats in Ferreting Out Some of the Laws That Govern the Various Motions

IN THE dead of night, just before dawn, the world seems at rest. Darkness and stillness envelop the earth. Traffic ceases. Human beings are in deep sleep; bird and beast are in their places of shelter. Even the fluttering and buzzing insects are stilled, nowhere to be seen. The dim outline of trees against the massive hill shows the trees as motionless as the hill itself; for the tireless breeze too has paused. In the heavens the fixed stars send out their feeble light upon an earth that for the moment seems deathlike in its quiet.

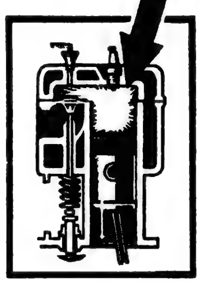
Yet beneath this outward calm the world is a seething, turbulent collection of moving bodies. The earth itself, we know, is spinning around on its axis. On its surface at the Equator the very mountains are being hurtled through space at a speed of over a thousand miles an hour. The entire earth is traveling through space around the sun at a speed of nearly twenty miles a second. The sun itself is not at rest; for it is spinning like a top, and in addition is carrying all the planets with it through space at a speed of twelve miles a second. Day and night the moon draws up the ocean's waters in the swell of the tide that dashes its foamy crests upon the shore. Nor are any of the stars really fixed; many move faster than the sun.

Upon close examination even the seemingly motionless things about us are found to be moving ceaselessly. Invisible currents of air move down toward cold objects and up from warm ones. Leaves sway gently to and fro. Within the fixed and solid trunk of a tree streams of water and nourishment are constantly coursing up and down from root tip to topmost leaf. Within the human body asleep, the heart still beats, the blood still flows, and the lungs still

breathe. Upon everything, at all times, invisible particles of dust fall; and the rivers never cease to run to the sea.

But the movement of things extends beyond our mere powers to see, to hear, and to measure. Every dead stick, every cold stone, as well as every living object, contains within it a storm of motion. The very molecules (mŏl′ĕ-kūl) of which all objects are composed are dancing to and fro. The warmer an object, the faster the dance. Nothing on earth has ever been so cold that this molecular (mō-lĕk′ū-lár) dance has been stopped. Inside an automobile engine or the cylinders of a locomotive it is the fierce dance of the molecules that pushes the pistons and gives them power. And even the air under ordinary conditions contains molecules moving so rapidly that they pound down with blows which, in their totality, cause a pressure of nearly fifteen pounds on every square inch of surface against which the air rests.

Associated Press Photo



When an automobile driver pushes down on the accelerator, he commands the combined physical power of a hundred men. By his act he opens a valve which allows a rush of fuel and air into the cylinders of his engine. There the mixture is exploded. Trillions of gas molecules are thrown into a furious dance. They pound against the walls of the cylinders, and against the pistons, which shoot downward as a result of the terrific pressure of the many dancing molecules.

As we study the ways of moving matter we can recognize at least three different styles of motion. First, there are the bulletlike flights in a straight line. Such motion is rarer than one might ordinarily believe; yet we meet with it now and again. A pistol or rifle bullet shot at a target at close range, or an arrow similarly released, travels practically in a straight line. The big-league baseball pitcher's "fast one" and the line drive that cracks off the batsman's bat are also examples of approximate straight-line flight. The straightest of all the motions we can see is the free fall of a heavy object to the ground.

Most large objects move in curved paths. Sometimes these curves are circles; more often, as in the case of planets, they are ellipses (ĕ-lĭps′). Frequently the paths take the shape of a curve which the mathematician calls a parabola (pȧ-răb′ō-lȧ). Such is the path which a baseball follows when thrown at an angle into the air, or the path which a shell takes when fired from the mouth of a cannon. There are other curves too, some so regular as to be well known to mathematicians; others so irregular as to defy description.

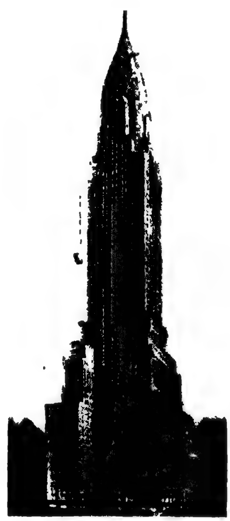
The third kind of motion is the most interesting of all. We might call it "to-and-fro motion," though physicists refer to it as "periodic motion." A swinging pendulum is an excellent example of this kind of motion. Watch it move. As the bob at the end falls, it travels in the arc—or small section—of a circle, picking up speed as it drops. When the pendulum rod or string hangs vertically, the speed of the bob is greatest. Then the bob begins to climb, losing speed until for a moment it is at rest. But only for a moment, since it falls again, picking up speed and then losing speed as before, until it finally reaches the starting point. Again and again the pendulum repeats this to-and-fro, falling-and-rising motion, while the speed of travel changes from zero at the high points to some maximum value at the low point.

To-and-fro motion of the kind illustrated by the pendulum just described is very common in the world about us, though we may not always recognize it when it occurs. Every time a sound is uttered or a musical

instrument played, the body which causes the sound, the air around this body, and our eardrums when the sound is heard, all move in the to-and-fro manner. We can appreciate how important such motion is when we realize that human speech, all music, the telephone, and radio loudspeakers, all depend upon and are explained by to-and-fro movement of particles of matter. Even more important does such motion become when it is applied to the field of electricity. There it makes possible the long-distance transmission of power, radio broadcasting, and television.

Photo by Underwood & Underwood

This boy is about to send the ball over the fence. In its flight the ball will follow a curved path. Mathematicians who have studied such curves call them "parabolas."



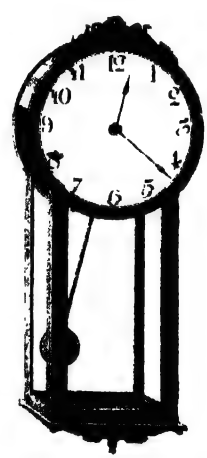
As we study the ways of moving matter we recognize a second style of motion; namely, motion in a straight line. A stone dropped from a height, as in the picture above, will travel downward in a straight line.

Johannes Kepler's claim to fame is often based on his work in astronomy, rather than physics; yet it was his life and work which more than any one thing made possible the discoveries of Galileo (găl'ĭ-lē'ō) and Newton—the founders of modern physics. Kepler was born in 1571, at a time when superstition and intolerance were rampant. Men were afraid to say what they believed if their beliefs contradicted the teachings of accepted authority. Persecution, ridicule, and even death were their punishment. The modern spirit of truth seeking through experimentation and the study of facts, had not yet been born, and would hardly have been understood even by the best thinkers of that day.

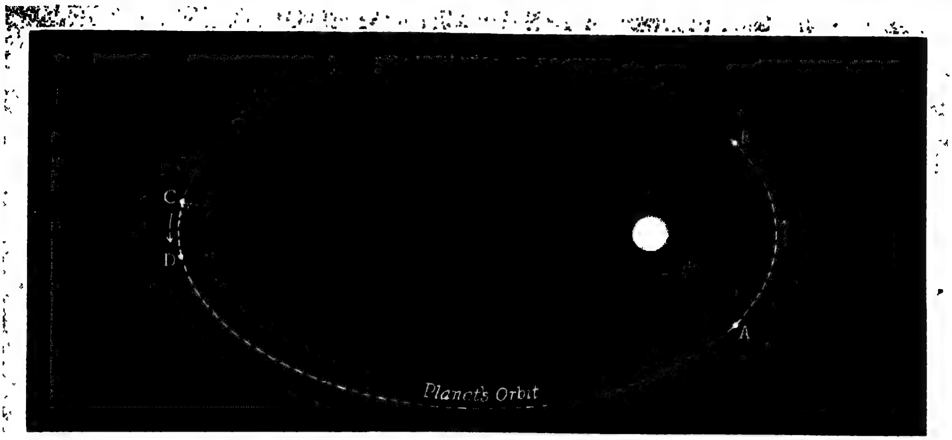
In early life, Kepler had the good fortune to study under the Danish astronomer, Tycho Brahe (tē'kō brä'ĕ), the greatest fact collector of his age. Brahe devoted a lifetime to making observations through a telescope and to recording these observations with the minutest care. When he died, he willed his tables of facts and figures to Kepler.

Now Kepler was greatly fascinated by the regularity of movement of the earth and other planets around the sun. Firm in the belief that a law of nature determined the planetary movements, the size and shape of their paths, and the speed of their travel, he set out to discover that law. The means at his disposal were the wonderful set of figures so painstakingly assembled by his teacher and friend, Tycho Brahe.

In the beginning, two things interfered with Kepler's success. In the first place, only five of the nine planets were known to him. He never dreamed that there might be others. Secondly, he assumed that the planets traveled in true circles around the sun. The circle had a strange and mystical meaning for men of his time; it was thought to be as a symbol (sĭm'bŏl), or representation, of perfection. What more natural than that the heavens should obey the law of perfection! For years Kepler slaved night and day, calculating and re-calculating, discarding and beginning again, only to find that if the planets really moved in circles, then all of Brahe's figures were



The third kind of motion is the most interesting of all. It is to-and-fro motion, such as is found in a swinging pendulum. Physicists refer to it as "periodic motion."



One of Kepler's conclusions as to how planets travel about the sun placed the sun at one of the "foci" of an ellipse. A planet travels from A to B in the same time that it takes to travel from C to D. Hence, planets move faster when close to the sun. Kepler proved that area No. 1 is equal to area No. 2.

wrong! But Brahe's figures did not depend upon theories; they were facts. Kepler could not doubt their reliability. Clearly, there was but one conclusion. Planets did not move in circles.

What Paths Do Planets Follow?

What sort of path, then, *did* they follow? An oval path, perhaps; and so he tried to fit his figures to an ellipse. It worked! Every observation of Tycho Brahe found its proper place. It was like fitting together all the pieces of a complicated jig-saw puzzle.

In this way Kepler solved the first great problem of moving bodies and gave to the world a set of physical laws that govern the movement of planets around the sun. Let us consider briefly what these laws are.

There are many ways of stating the conclusions which Kepler drew from the tables of facts and figures left to him by Tycho Brahe. Perhaps the simplest and most satisfying way is in the language of mathematics; but since few of our readers have as yet learned this advanced language, we shall try to express these ideas in words rather than in symbols.

Kepler's first conclusion was that all planets move about the sun in elliptical, or oval, paths, with the sun at one of the two center points, or "foci" (fō'sī), which all true ellipses have. Thus, each planet in the course of one complete revolution about the sun is constantly changing its distance from the sun. In the case of our own earth, this distance is sometimes as short as ninety-two million miles and sometimes as great as ninety-four million miles. When we refer to the earth as being ninety-three million miles away from the sun, it is the average distance we have in mind. The same change in distance occurs in the case of the other planets, though two of them travel in paths that are closer to the sun, and therefore shorter, while the rest of them travel in paths that are further away from the sun, and so longer than our own. The planet most distant from the sun and the one discovered only recently is called Pluto. Its average distance from the sun is about three billion, six hundred million miles.

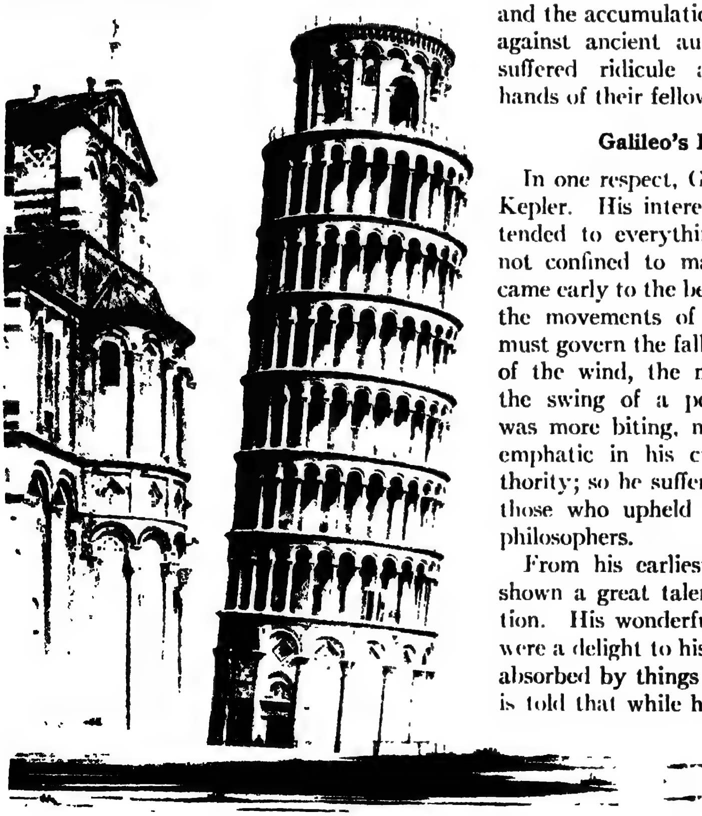
When Does a Planet Travel Fastest?

The second conclusion of Kepler had to do with the speed of travel of planets along their paths. Each planet travels faster when nearer the sun than when further away from it. An interesting way of showing just how fast each planet travels is to imagine a line drawn from any planet to the sun. As the planet moves, this line sweeps through a kind of triangular area very much like a piece cut from a round pie or cake. Now Kepler proved that the line we have just spoken of sweeps through equal areas in equal times. Thus, in the course of a month,

an imaginary line from the earth to the sun sweeps across a triangular area of a certain size and shape. During any other month, this line sweeps across a triangular area of different shape; but the size is the same. If these areas were pieces of pie, we should each month have a differently shaped piece of pie; but the amount of pie would be the same.

The third of Kepler's conclusions, or laws, had to do with the relationship that exists between a planet's distance from the sun and the length of time it takes the planet to complete one revolution. He found that if the time of revolution is squared—that is, multiplied by itself—and the distance from the sun is cubed—that is, multiplied by itself twice—then a direct proportion exists between the squared quantities and the cubed quantities. If this idea is not altogether clear to some of our readers, they can at least understand this: that Kepler had devised a way of calculating how far away any planet is from the sun by measuring the length of time it takes that planet to complete one trip around the sun and comparing it with the earth's time of revolution and distance from the sun.

Before a large assemblage of wise men, Galileo mounted to the top of the Leaning Tower of Pisa and released a half-pound weight and a hundred-pound cannon ball. Dropped at the same instant, they struck the earth at the same instant. This, he thought, was convincing proof that heavy and light objects fall with the same speed. But ways of thinking three hundred years ago were very strange—the wise men refused to believe what their eyes saw.

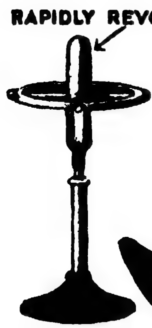


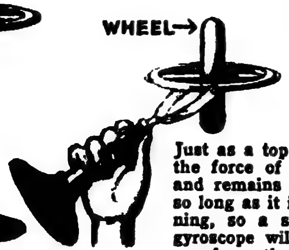
Galileo (1564–1642) was an Italian by birth. Throughout his life he was a great friend of Kepler, following closely all Kepler's work and communicating with him constantly about matters of science. The two men had much in common. Both were interested in astronomy, in the problems of matter in motion through space; both sought truth in nature through experimentation and the accumulation of facts; both revolted against ancient authority and as a result suffered ridicule and persecution at the hands of their fellow men.

Galileo's Laws of Motion

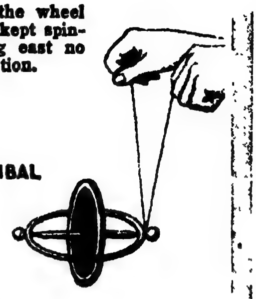
In one respect, Galileo was different from Kepler. His interest in moving matter extended to everything about him, and was not confined to matter in space. Galileo came early to the belief that if laws governed the movements of planets, the same laws must govern the fall of an apple, the blowing of the wind, the motion of the waves, or the swing of a pendulum. Also, Galileo was more biting, more sarcastic, and more emphatic in his criticisms of ancient authority; so he suffered more at the hands of those who upheld the writings of the old philosophers.

From his earliest childhood Galileo had shown a great talent for mechanical invention. His wonderful toys and little models were a delight to his friends. He was always absorbed by things that moved. The story is told that while he was still a young man, Galileo became interested in a certain swinging lamp which was suspended from



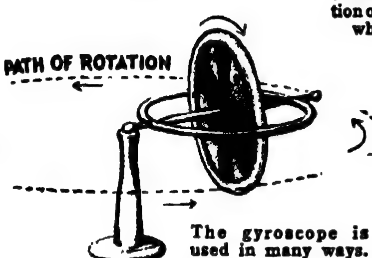


Below is a gyrocompass. If the wheel points east, let us say, and is kept spinning, it will keep on pointing east no matter what the ship's motion.

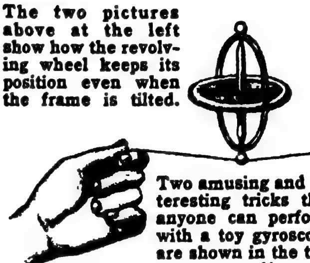


Just as a top resists the force of gravity and remains upright so long as it is spinning, so a spinning gyroscope will resist any force that tends to change the direction of the axis around which it rotates.

The two pictures above at the left show how the revolving wheel keeps its position even when the frame is tilted.

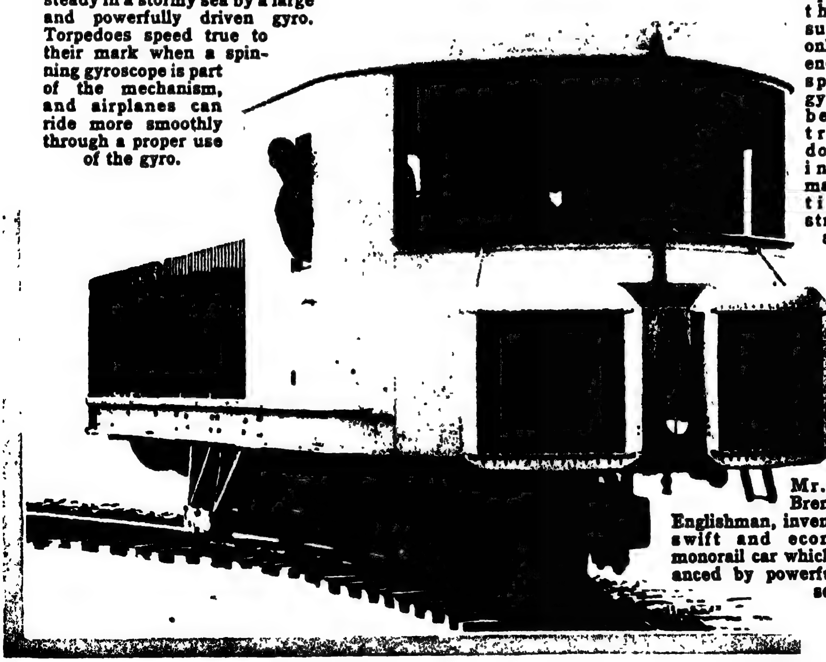


The illustration at the left shows what is known as a spinning gyroscope's "double motion" when it is allowed to revolve around a central point of support.



Two amusing and interesting tricks that anyone can perform with a toy gyroscope are shown in the two pictures directly above. At the top, a rapidly spinning gyroscope is holding itself up, even though supported only at one end. The spinning gyroscope below it travels down an incline made of a tightly stretched string.

The gyroscope is used in many ways. Attached to a telescope, it can keep the instrument pointing steadily at the stars, even though the support wobbles, as it would on a rolling ship. In fact, the ship itself can be kept steady in a stormy sea by a large and powerfully driven gyro. Torpedoes speed true to their mark when a spinning gyroscope is part of the mechanism, and airplanes can ride more smoothly through a proper use of the gyro.



Mr. Louis Brennan, an Englishman, invented this swift and economical monorail car which is balanced by powerful gyroscopes.

the ceiling of a cathedral. Instead of idly watching the to-and-fro motion, as many another boy would do, he studied closely the time of its swing. There being no watches in his day, he used the regular beating of his pulse as a means of timing the swings of the lamp. At once he ran into a puzzle. Why was it that the number of swings in a given time was always the same, whether the lamp traveled through a large arc or a short one? Could the number of swings in a given time be changed in some way? How?

Timing the Pendulum's Swing

And so he went home to experiment with swinging pendulums. He tied weights to strings and suspended them. He tried weights of wood and weights of metal; he swung them through short arcs and long arcs; he used round weights, cylindrical weights, and irregular pieces of stone; he made his strings long and short. To his surprise, he found that for small arcs only one thing changed the number of swings in a given time—the length of the pendulum. Later he carried his calculations to a point where he could predict in advance the rate of swing of any pendulum if he knew its length. Thus the law of the pendulum was discovered.

Even before the exact law was discovered, Galileo put his pendulum to practical use. If the beat of a person's pulse could be used to time a pendulum, why could not a swinging pendulum of known length be used to time a person's pulse. This, as one can well imagine, was a great help to the physician, and marks a great step in the advance of medicine.

Some years later, Huygens (hī′gĕnz), a Dutch astronomer, invented a pendulum clock; in this way Galileo's interest in matter that swings to and fro resulted in a means for timing more accurately the swing of heavenly bodies through space. The pendulum clock and the modification of it which we call a watch—for a watch is regulated by a to-and-fro balance wheel—are the timepieces which we use to this day. For it is only a few years since electric clocks were devised, to depend for their regularity upon a principle different from Galileo's pendulum.

Kepler's laws of motion in a curve and the law of to-and-fro motion in a pendulum caused Galileo to turn his attention to other kinds of motion. Soon he was absorbed in bodies that slide and roll downhill, and in bodies that fall straight to the ground. Among the writings of the famous Greek philosopher Aristotle (ăr′ĭs-tŏt″l) was the statement that heavy objects fall faster than light ones. This sounded like common sense. No one questioned the idea. No one would dare question the authority of Aristotle. But Galileo did dare to question. Like the true scientist he was, he experimented with falling bodies, measuring their weights and timing their fall. To his amazement, he found that Aristotle was wrong He could prove it. When the learned men heard of his idea that heavy and light objects when dropped at the same instant reach the ground at the same instant, they were up in arms. They scolded and threatened. They laughed and ridiculed. They brought Galileo to trial for his beliefs

Galileo accepted the challenge and requested that he be permitted to demonstrate the facts. Before a large assemblage of wise men he mounted to the top of the Leaning Tower of Pisa (pē′zȧ). Then, before their very eyes, he released a half-pound weight and a hundred-pound cannon ball. Dropped together, they fell together. He had triumphed.

But so strange were the ways of thinking in Galileo's time, that many of his audience, in spite of what they had seen, ran home to find the exact page and line in Aristotle's writings which denied the thing which Galileo had proved!

It took time, patience, and courage, as well as genius and hard work, to establish the method of science and to bring new knowledge to the world. Galileo was a pioneer—one of the very first to show the way. In the next chapter we shall learn more of his achievements and contributions, particularly about the ways of falling bodies and the reasons why matter moves as it does.

PHYSICS

Reading Unit No. 3

WHAT MAKES MATTER MOVE?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How do men succeed in jumping safely from great heights? 1–294

How fast do all objects fall in a vacuum? 1–295

What did Galileo use to time the speed of objects moving downhill? 1–295

What happens to the speed of an object as it falls? 1–296

What is meant by momentum? 1–297

Things to Think About

An object shot out horizontally and another object allowed to drop straight down from the same point at the same instant, will hit the ground together. Why?

How far will an object have traveled ten seconds after it has been dropped from a high point?

Picture Hunt

At what rate does the speed of a falling body increase? 1–296

How did Galileo defend himself and his ideas? 1–294

Related Material

What were Galileo's astronomical discoveries? 1–127, 148, 155-56

How did Galileo prove his theories? 1-294

Why do objects fall to the earth? 1 303

How can falling bodies be put to work? 1–369, 10–549

How is an automobile accelerated? 10–289

How did Newton discover the laws of gravitation? 1–103, 301

What is the famous story of the falling apple? 1–14

Practical Applications

How may the speed of a falling aviator be checked so that he may reach the ground in safety? 1–294-95

How may the acceleration of falling bodies be used in construction work? 1–296

Leisure-time Activities

PROJECT NO. 1: Show that two falling bodies which start to fall at the same time will reach the ground together, 1–295.

PROJECT NO. 2: Estimate the heights of buildings by timing the fall of small objects dropped from those buildings, 1–296.

Summary Statement

In order to make a body start moving, stop moving, or change its motion, a force is required.

Photo by Alinari

Because Galileo sought truth by experimenting rather than by referring to the writings of great men of the past, he was compelled to stand trial. Here we see him using actual facts in an attempt to prove that his beliefs are true even though they may contradict the writings of the older, accepted authorities.

WHAT MAKES MATTER MOVE?

"Force" Is a Push or a Pull Which Can Change the Motion of Matter; and This Story Will Tell You What Scientists Mean by the Word

FRED was puzzled. He had read the story of Galileo at the Leaning Tower of Pisa (pē′zȧ) and, of course, he was glad that the founder of modern science had triumphed. If, after more than three hundred years, the world still believed that heavy objects and light objects fall to the ground at the same instant if dropped together from the same height, then it must surely be so. He sympathized with Galileo because of the torture to which the latter was subjected and he admired the man for his heroic courage. But somehow he was dissatisfied. A little ashamed of his doubts, he waited until no one was looking and dropped a marble and a slip of paper from his study window. He heard the click of the marble as it struck the pavement; but there was his paper still fluttering on its way to the ground. He tried it again and again—and always with the same result. Was Galileo wrong, after all? When he dropped a small and a large marble together, he was not quite certain which struck first. He could not be sure that he had let them go *exactly* at the same moment. Then he thought of a parachute jumper escaping from an airplane in trouble. Recalling a motion picture he had seen, he remembered that the aviator first shot downward like any heavy stone, but that the opening parachute soon retarded the fall so completely that the man lighted gently upon the ground. Surely a man falls faster than does an open parachute; for if the strings are cut the man is killed. The more Fred thought about the matter, the more puzzled he became. Finally, he took his problem to Uncle John, who knew a great deal about science and liked to help boys with their experiments.

Uncle John smiled as Fred explained his doubts concerning the Leaning Tower of Pisa story. "Fred," said he, "let me see you drop your marble and paper." Quickly Fred produced from his pockets the necessary materials and ran to the window of Uncle John's laboratory. "Just a minute!" cried Uncle John. "Before you drop them, do you mind if I look at the slip of paper?" Surprised, Fred gave him what he wanted. For no apparent reason, his uncle proceeded

to crumple the paper in his hand until it was a tightly squeezed wad no larger than the marble. "Now, go ahead and drop them together," he said. "All right," said Fred, "crumpling the paper doesn't increase its weight." With head out of the window, Fred watched carefully. He was amazed to see that the paper hit the pavement almost as soon as did the marble. "Well, what do you think?" laughed Uncle John.

Does Air Make the Difference?

An idea suddenly dawned upon Fred. "I *think* I see," he cried. "Has the *air* anything to do with slowing up the paper when it is spread out?" "Well, now, that's a brilliant idea," said his uncle, "I wonder if we can put it to a test."

From a cabinet in the laboratory, Uncle John removed a long glass tube closed with a brass cap at one end but provided with a narrow nozzle at the other. Inside the tube, which was about an inch and a half in diameter and about three feet long, could be seen a round metal disk and a piece of tissue paper of the same size and shape as the disk. As the tube was quickly turned upside down, Fred could hear the clank of the metal striking bottom; but the tissue sailed downward slowly and gently. When it was inverted again, the same thing happened. The heavy metal fell faster than the light tissue paper.

"Now," said Fred's uncle, "let's get rid of the air in the tube. If there is anything in your idea that air retards the fall of objects, taking the air from the tube will prove something."

What the Experiment Proved

The nozzle end of the tube was then attached to an air pump, and the pump was set working until it seemed that most of the air must have been withdrawn from the tube. Eagerly, Fred inverted the tube. The disk and the paper fell together. They struck bottom at the same instant. Repeated trials gave the same result; but as soon as the air was permitted to enter the tube, its effect was to retard the falling paper much more than the falling metal, so that the metal struck bottom much sooner. Fred was delighted with the experiment, not only because he had learned something new —namely, that air offers a resistance to bodies moving through it—but because he now really understood why Galileo was right and Aristotle wrong.

If the wise men of Galileo's day had all been like Fred, it would have been a simple matter to make them believe that air resistance alone caused light bodies to fall more slowly than heavy ones. But we must not forget that while Fred lives in a world that has learned to seek truth by experiment, Galileo was a pioneer whose ways of thinking were strange and new to practically everyone.

Galileo's Experiments with Falling Bodies

In spite of ridicule, therefore, Galileo persisted in his beliefs and in his experiments. In order to learn more about falling bodies, he caused bodies to fall in many different ways. Once he arranged a contrivance by which he could shoot a ball outward horizontally while a second ball was released from the same spot to fall straight down. He was surprised to find that both balls hit the ground at the same instant. Of course, the first ball, having been given a horizontal push, landed some distance away; but in so far as the actual falling was concerned, it was the vertical height alone which determined the time of fall for both balls. Why was that? It began to look as if all bodies were being pulled downward in such a way that neither their weight nor any other push or pull upon them affected their speed of fall. That being the case, Galileo set up a long inclined plane down which he could roll a ball. The height of the top end of the incline was easily changed at will. The long slope contained a groove in which the ball could roll, and was marked off into equal units of distance. In order to measure the time taken by the ball in its travel down the slope, he arranged a pail of water with a small hole in the bottom. The water trickled out of the hole into a cup—the more time, the more water. He knew the length of time by weighing the amount of water in the cup. A very crude clock it was, to be sure—but this was in the day before modern clocks and watches.

With this arrangement, Galileo could now observe bodies that were forced to fall slowly; for that is what bodies do when they roll down an incline. And although they fell slowly enough so that Galileo could time them at every point, yet the same pull was operating upon them as the pull that is responsible for the more rapid fall of any object released from a height.

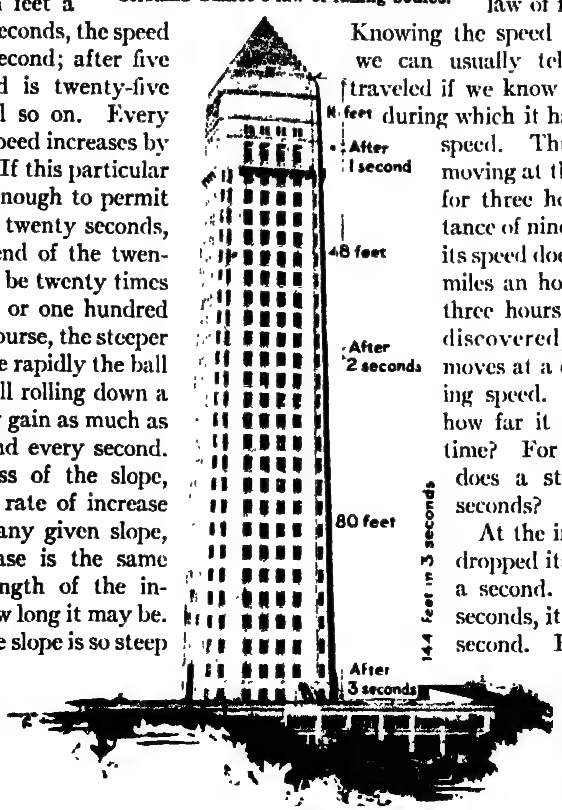
Our readers will be interested in the following table:

	A Body That Has Fallen for	Reaches a Speed of	And Has Covered a Distance of
(a)	1 second	32 feet a second	16 feet
(b)	2 seconds	64 feet a second	64 feet
(c)	3 seconds	96 feet a second	144 feet
(d)	4 seconds	128 feet a second	256 feet
(e)	5 seconds	160 feet a second	400 feet
(f)	6 seconds	192 feet a second	576 feet
(g)	7 seconds	224 feet a second	784 feet
(h)	8 seconds	256 feet a second	1,024 feet
(i)	9 seconds	288 feet a second	1,296 feet
(j)	10 seconds	320 feet a second	1,600 feet

The way to read the above table is as follows: Line "f"—"A body that has fallen for 6 seconds reaches a speed of 192 feet a second, and has covered a distance of 576 feet." Can you add line "k" to the above table, for "11 seconds"? Try it, in order to see if you understand Galileo's law of falling bodies.

What did Galileo learn from all his measurements? Merely this—that a ball rolling down an incline increases its speed at a constant rate. If, at the end of the first second, the ball is rolling at a speed of five feet a second, the speed becomes ten feet a second after two seconds. After rolling three seconds its speed is fifteen feet a second; after four seconds, the speed is twenty feet a second; after five seconds, the speed is twenty-five feet a second; and so on. Every second, then, the speed increases by five feet a second. If this particular incline were long enough to permit the ball to roll for twenty seconds, the speed at the end of the twentieth second would be twenty times five feet a second, or one hundred feet a second. Of course, the steeper the incline the more rapidly the ball gains speed. A ball rolling down a very steep hill may gain as much as fifteen feet a second every second. Upon the steepness of the slope, then, depends the rate of increase in speed; but for any given slope, this rate of increase is the same throughout the length of the incline, no matter how long it may be.

Now, suppose the slope is so steep as to be vertical. The ball then falls freely to the ground. What is its rate of increase in speed? Galileo found this to be exactly thirty-two feet a second for every second. This was a very important discovery. Galileo could now say that all bodies, heavy or light, when dropped from a height, fall with an ever-increasing speed. After one second of fall this speed is thirty-two feet a second. At the end of the second second of fall, the speed has become sixty-four feet a second; at the end of the third second of fall, the speed is ninety-six feet a second; and so on. Every second the speed increases another thirty-two feet a second. A body falling freely to the ground for ten seconds strikes the ground with a speed of 10 times 32 feet a second, or 320 feet a second. Thus, Galileo had discovered a law of falling bodies.



Knowing the speed of a moving body we can usually tell how far it has traveled if we know the length of time during which it has maintained that speed. Thus, an automobile moving at thirty miles an hour for three hours, covers a distance of ninety miles, provided its speed does not vary from 30 miles an hour throughout the three hours. But, as Galileo discovered, a falling body moves at a constantly increasing speed. How can we tell how far it travels in a given time? For example, how far does a stone fall in three seconds?

At the instant the stone is dropped its speed is zero feet a second. At the end of 3 seconds, its speed is 96 feet a second. Hence, its average speed for the 3 seconds is 0 plus 96 divided by 2, which is 48 feet a second. Thus, the stone travels at an

average speed of 48 feet a second for 3 seconds, covering a distance of 3 times 48, or 144 feet.

Even if we grant that Aristotle was wrong about the speed of falling bodies and that Galileo was right, there yet remains a difficulty to be cleared away. As someone once put it, "If I am to be hit on the head by either a tennis ball or a baseball dropped from a window, I should much prefer the tennis ball, even though both have the same speed when they strike me." In some way, the heavier ball possesses more *motion*. When it is stopped, it exerts a greater *force*. Galileo gave considerable thought to this phase of the problem. In order to solve it, he devised a new term, which has played an important part in the science of physics. He called the amount of motion possessed by a body, its "momentum" (mō-mĕn'tŭm). Momentum is the combined effect or the product of two things: speed and weight—though later Newton showed us that "mass," rather than weight," should be used in defining momentum. A good illustration of momentum may be seen on the football field, where fast-running, heavy men are considered the best players. A light man must hit his opponent with great speed if his tackle is to be successful. Often such a player brings down a much heavier man if the heavy man is moving slowly. But a heavy end tearing down the field at high speed is irresistible. His momentum—his speed multiplied by his mass—is greater than that which the other side can bring to bear against him.

Again we see the effect of momentum when a small automobile collides with a heavy bus. The bus may not be moving so fast as the smaller car; but the damage is inflicted chiefly on the body which has the least momentum. In this case, the automobile has less momentum because its mass is so much smaller than that of the bus.

If Galileo were asked to answer the question raised by the title of this chapter, he would most certainly reply in one word—Force! Force makes matter move! And, if he were asked to explain what he meant by "force," he would probably say that force is that which can change the amount and kind of motion of a body, or its momentum.

It would be well if the reader became familiar with this idea of force, because that is what scientists mean whenever they use the word. Unfortunately, the term is often confused with others in ordinary language. The words "strength," "power," "energy," "effort," as well as several others, are sometimes used interchangeably with "force." In physics, however, we must learn to distinguish clearly and exactly among such terms as force, power, energy, etc. The mark of a scientist is the care with which he defines each special word that he uses.

After a scientist has made many observations and has arranged experiments to check these observations, there comes a time when he tries to tie all his facts together. In doing so, he tries to make all observations and all facts follow from one law, hypothesis (hī-pŏth'ē-sĭs), or explanation. Galileo was now ready for such a step. What makes bodies fall as they do? What makes a pendulum swing as it does? What makes the heavenly bodies move as they do? In each instance, he saw that the facts could be explained if he assumed the existence of some constant and ever-acting force—a force that makes the planets move around the sun; a force that makes the pendulum swing; a force that makes bodies fall. Is it the same force in each case? Galileo did not know. He had not enough facts as yet. That discovery was to be made by his successor, the second great founder of modern science, Isaac Newton. Galileo did, however, continue to gather facts about forces which make bodies move. His brilliant mind saw meanings in these facts which he expressed in language so clear that it has never been improved upon. Also, he added several new terms which have been of the greatest help to scientists from Newton down to Einstein.

The work of Galileo is put to use by every engineer who designs a bridge, a skyscraper, a subway, or an automobile. It may well be said that modern civilization is built upon his ideas as developed by Isaac Newton.

PHYSICS

Reading Unit No. 4

THE FORCE THAT HOLDS THE UNIVERSE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the distance between the moon and the earth? 1–300
Where might objects fall to the moon instead of to the earth? 1–300
How does every object affect every other object? 1–301
What do we know about gravitation? 1–302
What determines the gravitational attraction between two objects? 1–302-3
What would a man weigh on the surface of the sun? 1–303-4
What is the difference between weight and mass? 1–304

Things to Think About

At what speed would a rocket have to leave the earth in order to overcome completely the earth's gravity?
Why do objects on the earth possess weight?
How may gravity help to produce an electric current?
What does gravity have to do with snow, rain, hail, and sleet?

Picture Hunt

Where is up? 1–300
How high could you jump from the surface of the sun or from the surface of the moon? 1–301

Related Material

How does gravitation cause the tides? 1–134
Why do the planets continue to revolve around the sun? 1–106
How does gravity make it possible for us to put water to work? 1–352
How was flour ground in England in colonial times? 9–233
How is falling water put to work most efficiently? 1–370
How does gravity affect things in the ocean depths? 1–67

Practical Applications

How is the energy of flowing water turned into electricity? 1–303, 506-8
How is gravity used to load trains, trucks, and boats? 1–304

Leisure-time Activities

PROJECT NO. 1: Put six magnets inside a hollow geography globe so that the poles face the surface. Cut a very small outline figure from sheet iron and place the little figure at the different poles. This shows how the force of gravity works.

PROJECT NO. 2: Make a power house, 14–37.

Summary Statement

Every object in space exerts a pull upon every other object.

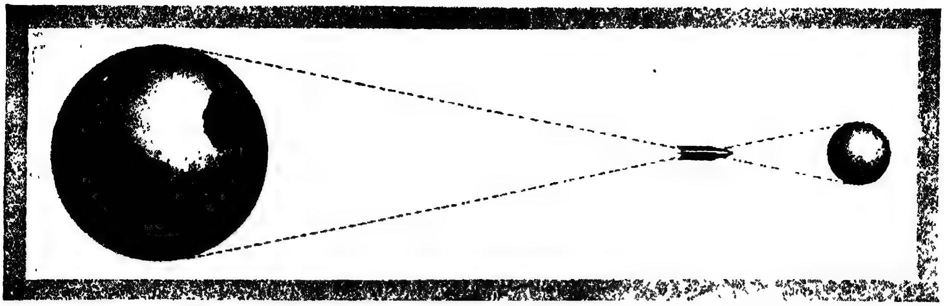
If ever we succeed in paying a visit to the moon, it will probably be in a rocketlike, stream-lined, gas-spouting ship like the one above. In our story we speak of such a ship as making the trip in the year 2042—about one hundred years from now. Who knows? Many scientists, all over the world, are trying hard to design rockets that will escape from the earth's gravitational pull and be free in space.

The FORCE THAT HOLDS *the* UNIVERSE

The Great Forces That the World Must Reckon with Can Move Bodies or Can Stop Them; They Can Help Man or Can Hinder Him

IN THE year 2042 A.D., the world held a grand celebration. Four hundred years had passed since the birth of the greatest physicist of all time. In the course of four centuries mankind had learned to appreciate the genius of Sir Isaac Newton and to be grateful for what he had done to benefit the race. Since the civilized world owed much to science, it was thought fitting and proper that the celebration should itself be of some benefit to science. Strangely enough, the year of Newton's birth was also the year of Galileo's death; it was not strange, therefore, that both founders of modern science should have a place in the hearts and minds of those who sought to make the year 2042 a memorable one.

The great climax of the celebration was the shooting of a rocket to the moon. The rocket was large enough to house a group of several observers, willing to leave the earth perhaps forever, willing to be killed ingloriously if anything went wrong. The engineers and scientists who planned the flight based their calculations upon the laws of motion discovered by Galileo and Newton. To shoot a projectile with sufficient force to overcome the earth's gravitational pull and to send a party of well-equipped observers to the earth's nearest neighbor in space, was

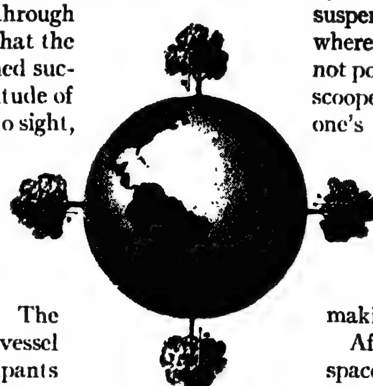


When our rocket of the year 2042 arrived at a point in space some 70,000 miles from the moon, the pull of the earth upon the rocket was about equal to the pull of the moon upon the rocket.

perhaps the crowning realization of the dreams and hopes of the men whose lives were being honored.

There is not space enough here to tell of all the experiments and other preparations which preceded the flight. Nor can we stop to describe the rocket and the method by which it was driven through space. It is enough to say that the "Ship of Space" was launched successfully before a vast multitude of people, that it was soon lost to sight, and that nothing was heard from it for twenty days. Then, one morning, the world was startled with the news that the rocket had come back. It had fallen into the Atlantic Ocean. The captain of the rescuing vessel found but one of the occupants alive; and the latter told a story the like of which had never before been heard on earth.

The rocket had started quite successfully. Gradually, its speed was increased until it moved at about a thousand miles an hour. Such speed was easily maintained, once the earth's atmosphere was left behind. The observers were fascinated with the view of the earth becoming smaller and smaller. For the first time man was able to see his planet as a sphere, and to identify the continents as they are shown on maps. After a week of travel at this great speed, nearly 170,000 miles had been covered. The moon was only about 70,000 miles away.



What is "up"? What is "down"? That depends upon where you are. Four men, each under one of the trees shown above, would swear that *his* tree pointed straight "up." And they would all be right!

It was here that a great difficulty arose, not with the machinery of the rocket, but with the men inside. Having reached a point where the pull of the moon was equal to that of the earth, many strange and amusing things began to happen inside the rocket. Objects ceased to fall, but remained suspended in mid-air, no matter where they were placed. Water did not pour out of bottles; it had to be scooped out and be pushed into one's mouth. Dressing and undressing became a problem, as did every other ordinary act of daily living. If one rose too suddenly from a chair, one found himself floating toward the ceiling, making frantic efforts to descend.

After a while, the pioneers of space accustomed themselves to these strange conditions and were much amused by them—so much so, that they made their grand mistake. They shut off the power of the rocket, so as to remain longer in this interesting position between earth and moon. For the first time in their lives they were free from the pull of the earth and they intended to take advantage of the fact. Foolishly, they delayed their arrival on the moon, spending their precious fuel to make excursions in directions perpendicular to their original line of travel. Perhaps they dreaded what awaited them on the bleak and lifeless moon; perhaps they despaired of ever being able to return to earth. At any rate, they soon real-

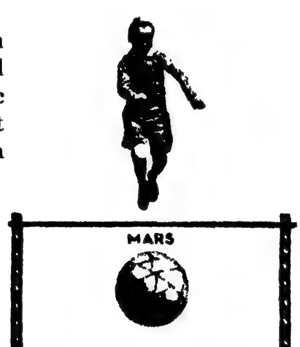
ized that their fuel supply was insufficient to complete the journey. They then decided to turn about at once.

The return trip soon brought them within the grip of the earth. The pull became stronger and stronger. Now they were *falling* to the earth. The power of the rocket was of course reversed so as to keep them from going at more than a thousand miles an hour. It took more than a week to return, and at the end of the time the fuel supply was almost exhausted. It was doubtful whether a terrible crash could be prevented. Careful maneuvering brought the rocket over the ocean and it plunged into the water. The force of the impact killed all but one of the occupants. When the rocket floated to the surface, the sole survivor had barely strength enough to open a trapdoor and attract the attention of a passing ship.

One of Newton's Greatest Ideas

We trust that our readers will pardon us for telling a story so much of which is pure imagination. Yet it can do no harm to speculate about the possibilities of the future in science. In fact, if we think carefully and thoroughly about the different elements in the story, we may be in a position to understand better one of Newton's greatest ideas.

Galileo's experiments with bodies that swing and fall caused him to decide that some force was exerting a constant pull upon everything. Newton pondered long and deeply over these experiments and over the laws of Kepler, too. He performed experiments of his own. He came to the conclusion that every object on the earth and in all space, for that matter, exerts a pull upon every other object. The sun pulls upon the earth and the earth upon the sun; the moon upon the earth and the earth upon the moon. An apple falls from a tree because the earth pulls it down; but in falling the apple too pulls upon the earth. If one asks why the earth does not fall toward the apple, the answer is that it does, but so little as to be



How high can you jump? The world's record so far is about seven feet. In this jump an athlete takes a running start and at the right instant pushes away from the earth with all his strength. Up he goes—but immediately the earth exerts its gravitational pull upon our would-be record breaker.

As our athlete soars into the air, the speed of his upward leap is quickly reduced. When only four feet from the ground, he has lost most of it, and by the time he has reached the bar, six feet above the earth, he can barely bring his feet over it before gravity begins relentlessly to pull him down again. Immediately he begins to fall, and down he crashes with ever increasing speed until he lands at the same speed with which he left the earth. But if this same athlete were to go to the moon and there attempt to try his skill at high jumping, he would have a much easier task. We have to assume, of course, that he *can* get to the moon, that somehow he is able to live in the vacuum which we believe to exist there, and that he brings with him all his skill and muscular strength. The same effort which he exerts upon the earth will on the moon carry him to a height six times as great. Instead of setting the record at six and a half feet, he will now be able to jump over a bar thirty-nine feet high, for the gravitational pull on the moon is only one-sixth of that on the earth. His leap will not be quite so spectacular on Mars, although it will be considerably better than he can do on earth. The gravitational pull on Mars is only one-half of that on earth. And so the arithmetic is really very simple—he will, with the same effort, be able to clear a bar thirteen feet high.

Photos by H. Armstrong Roberts

unnoticeable, since the amount of matter in the apple is so small in comparison with the amount of matter in the earth. Newton called this force of attraction between all pieces of matter, the "force of gravitation." His calculations showed that the extent of this force depends upon the amount of matter involved. One can determine the size of the force attracting one mass toward another by first multiplying the amounts of mass pulling upon each other. Thus, in order to calculate the force of gravitation between a two-pound stone and a three-pound cannon ball, one must first multiply 2 by 3.

But Newton discovered another fact. The distance between the attracting objects was also important. The closer two masses are to each other, the greater the force of gravitation. Bring one of two objects twice as near to the second object as it was to start with, and the pull is four times as great. Bring it three times as near and the force of attraction is nine times as great—four times as near, sixteen times as great; five times as near, twenty-five times as great; and so on. We must note that "four" is the square of "two"; "nine" is the square of "three"; "sixteen" is the square of "four"; "twenty-five" is the square of "five"; and so on.

All this Newton was able to say in one statement, which has since been called, the "Law of Gravitation." This is how he put it: "Any two bodies in space attract each other with a force which is calculated by multiplying the amounts of mass and by dividing the product by the square of the distance between the two bodies."

If we apply this law to the rocket which traveled to the moon, we can see that both the earth and the moon exert a pull on the rocket. Furthermore, the pull of the moon opposes the pull of the earth. Which pull is stronger? That depends upon where the rocket is and upon how much greater is the mass of the earth than that of the moon. If the masses were equal, there would be a point just halfway between the two about 120,000 miles from the earth—where the pull on the rocket in one direction would be exactly equal to the pull in the opposite direction. But, as we saw, these are exactly equal at a point about 170,000 miles from the earth and 70,000 miles from the moon. This means that the earth has more matter—that is, a greater mass—than the moon.

Let us suppose that you weigh 100 pounds on scales somewhere on our planet, the earth. Then let us suppose that you take an imaginary trip through space, first to the moon, then to the planet Mars, and finally to the sun. At each stopping place you weigh yourself. Were all this possible, you would be amazed to discover that you weighed only about 16 pounds on the moon, from 35 to 50 pounds on Mars, and from 2,600 to 2,800 pounds on the sun. The different gravitational pulls on the various bodies account for the differences in your weight. The sun, you will note, exerts a pull nearly 28 times as great as the earth's.

Where Would an Object Have No Weight?

You will recall that when the rocket reached a point 170,000 miles from the earth, objects inside the rocket seemed to lose all their weight. They floated in mid-air. So did the men inside. Had there been a weighing scale, and had a 180-pound man stood upon it, what would he have weighed? Probably nothing at all. This would be very amusing, of course; but also very puzzling. A man, a book, a glass, or any other object is made of matter. The amount of matter in these objects does not seem to change

whether they are on the earth's surface or 170,000 miles out toward the moon. The "weight" of these objects, however, *does* change; it even becomes zero when placed at the proper point between earth and moon.

The Difference between Weight and Mass

Issac Newton was the first to make a distinction between the "weight" of an object and its "mass." The mass of a person's body is the amount of matter in it; but a person's weight is the amount of pull which the earth exerts upon his mass in accordance with the law of gravitation. This pull, and therefore the person's weight, can and does change. The mass does not.

Thus, one grows heavier in traveling from the Equator toward the Poles, because the earth is somewhat flattened at the Poles, and the Poles are therefore nearer to the earth's center than is the Equator. Also, one loses weight when at the top of a tall mountain, since at high elevation one is further away from the earth's center. It has been calculated that a person weighing a hundred pounds loses about two ounces at a height of three miles.

On the surface of the moon, a 180-pound man would weigh about one-sixth of what he weighs on the earth, or thirty pounds. If it were possible to live on the moon, walking, running, jumping, lifting, throwing, and swimming would require much less effort there than upon the earth. On the moon, most of our readers would be able to break the world's record for high jumping, for a four-foot jump on the earth would be equivalent to a twenty-four foot jump on the moon.

What a Man Would Weigh on the Sun

On the surface of the sun, however, a 180-pound man would weigh 28 times 180 pounds, or 5,040 pounds. The gravitational pull of the sun is much greater than the earth's. So great in fact is the pull of the sun that a human being there would hardly have sufficient strength to lift his feet in walking, even if we grant that he could withstand the tremendous heat.

In speaking of the earth's pull upon objects near its surface, we refer to the force as "gravity" (grăv'ĭ-tĭ). The term "gravitation" is used for the force of attraction which acts between all bodies everywhere. Now, from one point of view, gravity is a great hindrance to mankind. Often it is a nuisance—even a menace. Always there is the danger of falling. If a road is steep, steps are built and a hand rail set up, to be handy in case one should slip. Objects are placed well away from the edge of a table and a protective wall is usually built around the roof of an apartment house. In the autumn we have to clear away the leaves that are strewn over the lawns; and in the spring, freshets rush madly over the countryside. Rain, snow, and hail batter the earth as they come down from the sky, and occasionally, at night, we see a meteor—a "shooting star"—being pulled into the earth by the force of gravity.

The Mysterious Pull of Gravity

In the house we are forever cleaning because dust never ceases to fall. We grow weary from climbing stairs and from lifting heavy objects. When an expensive vase drops and breaks, the real culprit is gravity. So, too, we can blame gravity when a collar button slips out and rolls away, or when we lose our balance on skates or on a bicycle. Going downhill in an automobile we apply the brakes, and going uphill we are fearful lest the engine stall. Because of gravity we supply airplane passengers with parachutes. Submarines sink, never to rise, because they have been overcome by gravity. When we show impatience at the ugly pillars which prevent a good view of the stage and which mar the beauty of the auditorium, we are annoyed because gravity is ever acting.

How Water Makes Our Light

But the water which falls over Niagara is used to drive wheels, the wheels turn dynamos, and the dynamos furnish light to homes and streets a hundred miles away. When gravity endangers a weakened structure, the wreckers come and build long wooden chutes down which gravity may pull the wreckage into waiting trucks. On the fiftieth floor of a building you slip a letter into a slot, and it is whisked away by the force of gravity to

the mail box down below. The locomotive engineer shuts off the power and lets gravity pull him down grade for miles at great speed. The man who delivers the coal attaches a slide from wagon to cellar and gravity draws the coal into the bin. If the last few pieces are caught in the wagon, the man cranks the wagon so that it tips at a greater angle. Gravity takes care of the rest. We depend upon gravity to help swing the clock pendulum. And we must not forget to thank the force of gravity for the thrills in a ride on the "scenic railway."

A Law for the Whole Universe

We have already seen how Newton's force of gravitation explained the law of falling bodies. It also made Kepler's laws clearer and more understandable. Man could now appreciate why the sun and the planets hold to their eternal courses. The force of gravitation is ever acting and exerts its power on all bodies in space, whether these bodies are specks of dust or giant stars. Newton made it possible for mankind to see itself living in a world of law and order. The stars, the sun, the planets, the earth, and the moon obey the universal law of gravitation. Man also must live his life subject to this law.

Understanding brings power. The fact that man had found a way of calculating the force of gravitation encouraged him to study his surroundings further and to plan his life so as to be in accord with nature's ways. He soon learned to build bridges and skyscrapers that withstand the pull of gravitation. He built highways, railroads, waterways, and vehicles to place upon them, always reckoning carefully upon the great force and taking advantage of it where possible. But more important even than the wonderful machines and structures which Newton made possible was the new idea which he brought into the world. He made us see that nature is understandable, that things happen because they are caused to happen; and that even when we do not know the cause, it is wiser to continue our search than to jump to a conclusion not based on fact and reason. Thus Newton began the great work of ridding the world of superstition and intolerance.

In passing, it may be well to say that, fine as was Newton's theory in helping us to understand what happens in everyday life, there was something about the theory which even Newton himself questioned. The problem was this: How can there be an attraction, or pulling force, without anything for the puller to pull with or for the pulled to be pulled by? How can the sun exert its pull on the earth across millions of miles of empty space?

It was not until 1913 that a satisfactory answer to the question could be given. When it appeared, it proved to be a modification of Newton's theory, and was proposed by Dr. Albert Einstein (īn'stīn), a man of whom both science and mathematics may well be proud. The new theory was called the Theory of Relativity (rĕl'ȧ-tĭv'ĭ-tĭ). This theory did not deny the truth of Newton's *law* of gravitation, but it gave us some new ideas of the exact *nature* of gravitation.

When Einstein came to work out the mathematics of his new theory he found that it generally agreed with the mathematics of Newton's theory. In one or two very special cases, however, it differed by tiny amounts. For example, Newton's theory would have the planet Mercury going about the sun in an ellipse. The Relativity Theory, however, required that we know still another fact about the planet. If the theory was right, the planet should also be spiraling about the sun in such a way that the axis of its orbit was slowly shifting. Furthermore, Einstein predicted that the positions of the stars nearest the sun, visible at the time of an eclipse, should appear to be shifted. As soon as these deductions were announced, astronomers worked feverishly to gather the facts that would prove or disprove them. When all the facts were in and analyzed, Einstein's predictions were found to be true, and the Theory of Relativity was accepted by scientists everywhere.

We now realize that Newton's laws are very nearly correct, certainly for everyday happenings related to gravitation. But we have also found that a better understanding of many other things in physics is made possible by the Relativity Theory. It is especially valuable in astronomy, where it comes nearer to the truth than any earlier explanations offered by scientists.

PHYSICS

Reading Unit No. 5

WHAT ARE THE LAWS OF MOTION?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is meant by inertia? 1–307

What is necessary in order to stop a body or to put a body into motion? 1–307-8

Why does not the sun stop the motion of the planets? 1–309

What is meant by centrifugal force? 1–310-11

What keeps the planets from falling into the sun? 1–311-12

How are automobiles equipped to overcome inertia? 1–312-13

Things to Think About

Why may an infielder be thrown off his balance when he catches a fast line drive?

What would happen to a racing car on a race track if the curves were not banked?

Why do you lurch backward when the car in which you are riding starts suddenly?

Picture Hunt

How may a hammer head be tightened on its handle by making use of inertia? 1–309

What happens to a person standing in a car that stops suddenly? 1–308

Related Material

How do brakes operate to stop a car? 1–461, 462, 10–196, 291

How does an automobile overcome inertia? 1–331

Under what circumstances may a perfect automobile stall? 1–307, 312

How are gears used to overcome inertia? 1–330-31, 10–289

What part does centrifugal force play in the universe? 1–6, 13, 15, 16

How great is the centrifugal force acting on the moon? 1–122, 136

Practical Applications

How do magicians make use of inertia on the stage? 1–306-7

How may centrifugal force be used to pump water? 1–465

Leisure-time Activities

PROJECT NO. 1: Show the power of inertia by performing the coin and card trick, 1–307.

PROJECT NO. 2: Demonstrate centrifugal force with a bucket of water, 1–312.

Summary Statement

A body at rest tends to remain at rest and a body in motion tends to remain in motion and continue in the same direction. Every action has an opposite and equal reaction.

Photo by British Information Services

The men who made this playground equipment for the war-torn city of Reading, in England, had only lumber and metal from bombed-out buildings to work with. But they understood the laws of motion and so were able to build devices that would give the children fun even though the skies might rain bombs after they all had gone to bed. Read our article and then see in how many ways the laws of motion are helping the children to play

WHAT ARE *the* LAWS *of* MOTION?

If You Wish to Know How Much Force to Exert, First Find Out How Much Change in Motion You Desire

WHEN all the refreshments had been served and eaten, it was time for games. No birthday party is complete without them; and Jack, in whose honor the gathering had been called, was ready with a large assortment of interesting things to do. But before he could begin, it was necessary to clear the dish-laden table. That made him think of an amusing "stunt" with which to start the festivities.

"Listen, everybody!" he called. "Do you know that it is possible to remove the tablecloth without first removing the dishes? Who would like it done?"

There was a chorus of "I's," followed by much skepticism and laughter from the guests. A few, knowing Jack's rashness, hoped to prevent the calamity which they knew would befall every dish on the table. But their arguments did no good.

With much assurance Jack declared, "Why, there is a law of science which says it can be done. They call it 'inertia,' I believe. Just wait and see!" Grabbing the edge of the tablecloth and bracing himself on the floor, he was about to give the cloth a terrific yank, when his mother came into the room.

"Stop!" she cried in great alarm. "Whatever are you doing? Do you wish to ruin the whole house?"

Jack stopped; but only to explain the situation carefully to his mother. He begged her to let him prove that he was right. His friends stood about, grinning and chuckling, and that made him the more eager to convince them. His mother listened long and patiently, but slowly shook her head. Apparently it required more than a law of science to make her part with her favorite tableware.

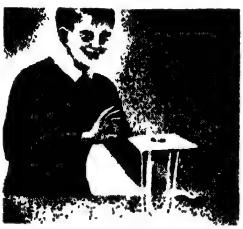
Faced with such stubbornness in a direction where he knew from experience no change of mind was likely, he hit upon a different plan to gain his end.

"All right. I'll prove to everybody's satisfaction that this can be done, without using the dishes and the tablecloth." Standing an empty drinking glass on the table, he covered it with a square of cardboard. On top of this he laid several coins. Then he snapped his finger sharply against the cardboard. The latter flew out under the blow and landed several feet away. The coins, however, remained behind, falling to the bottom of the glass.

The trick seemed to interest the group. Several hastened to try it themselves. There

was no denying the fact that the cardboard was removed from under the coins without changing the position of the coins. But Jack was not satisfied. "Now, watch this!" he cried.

This time he spread out his handkerchief on the table. Upon the center of the handkerchief he placed a glass of water. "Make believe the glass of water is a pile of dishes and that my handkerchief is the tablecloth." Saying this, he gave a sudden and sharp yank on the kerchief. The glass of water shook a bit, but was left standing where it was. Jack waved the make-believe tablecloth in triumph.



Bodies at rest tend to remain at rest
When the boy snaps the card with his finger, the card flies off the glass; but the coin which was resting on the card does not go with it. Since the coin was at rest, it tends to remain at rest. The card slides out from under the coin, which then falls into the glass.

Of course everyone was pleased, even Jack's mother joined in the applause. Fearing that he might be encouraged to try the trick on the real dishes, she hastened to suggest that some day, when Jack grew strong enough to pull a tablecloth as hard as he had pulled the handkerchief, she would be glad to let him experiment with the dishes.

Our readers will undoubtedly guess that the purpose in telling about Jack's trick was to introduce the first of Newton's laws of motion. Like all great truths, the idea sounds very simple. One almost wonders why it was dignified with the name "law." Of course, a body at rest remains at rest! Why not? If no one touches an object why should it not stay in its place? Yet the first law of motion is not quite so simple as that. The more we inquire into its meaning, the more meaningful it becomes. Let us, therefore, give the matter a little more thought.

A body at rest remains at rest unless a *force* is exerted to make it move. A force, then, is always responsible for the change from rest to motion. When Jack snapped his finger against the cardboard, he applied a force to the cardboard, but not to the coins. The coins, therefore, tended to remain at rest. The cardboard changed from a state of rest to one of motion.

We once knew a boy who boarded a trolley car with skates attached to his shoes. He skated to the front and remained standing, looking out on the road ahead with the motorman. When the car started he was amazed to find himself skating backward toward the rear. As a matter of fact, he was doing no such thing. He was standing still. The car was riding forward under him. In order to save himself from going out through the rear door he clutched at a strap. Then it was that the force of the car was also applied to his body; for as he stopped moving with respect to the car, he felt the yank of the strap on his arm. It required a force to change his state of rest to one of motion. He was now moving with the car.

When the head of a hammer is loose on its handle, a good way to tighten the head is to strike the end of the handle a sharp blow. The handle moves forward, but the head tends to remain at rest. Thus, the handle is wedged further and more tightly into the head.

Why an Automobile Engine Stalls

One of the annoying experiences that come to everyone who is learning to drive an automobile, is the stalling of the engine in starting. A large force must be exerted to overcome the inertia (ĭn-ûr'shĭ-ȧ) of rest in the heavy vehicle. This force is often too great for the engine; and unless the clutch is released slowly and the gas supply increased gradually, the car is stalled.

Now there is a second meaning to be found in Newton's first law of motion. Just as it requires a force to start a body moving, so it requires a force to stop a moving body—to change its state from motion to that of rest.

Considering once more the boy on skates in the moving trolley car, we find that he

John is stealing a ride on the back of a truck. But he forgot to take off his skates. Of course he didn't bother his head about Newton's first law of motion. Let us see what happens to him.

Suddenly the truck starts off. John's body was at rest and therefore tends to stay at rest. Before he realizes it, the truck is moving under his feet, and only the chains save him from a fall.

Straightening up and holding fast to the chain, John waits until the truck picks up speed. Then he is comfortable once more. He is moving with the truck. He even puts his hands in his pockets again. But suddenly a STOP sign appears in the road!

The driver puts on the brakes and John is hurtled forward. His body was in motion, and tended to keep on moving. For the rest of the ride John decides not to fight the first law of motion any longer, and holds tightly to the cab of the truck.

can release the strap as soon as he is moving with the car. He soon forgets about his early experience and stands at the rear of the car facing forward. Then the trolley comes suddenly to a halt. Does he halt with the car? Not at all. He continues to move, so that in a moment he has collided with the motorman, having skated the entire length of the car without meaning to do so. After that, he never released his hold on the strap. But that, too, was not altogether satisfactory. Every time the car stopped, his feet continued to skate forward, while his hands wrenched at the strap. He was a ludicrous figure, and swore never again to board a trolley on skates. Since there was no available seat, he solved the problem by taking off his skates.

It often happens in an automobile collision that the driver is hurled through the windshield or has his ribs broken against the steering wheel. Here, too, we find that the driver tends to keep on moving, even though the car is brought forcibly to a halt. The pressure of the windshield or steering wheel is required to bring the driver's body to a stop.

Another way to tighten the loose head of a hammer is to hold it, head up, and to slam down the handle end on the bench. When the rapidly moving handle is brought to a sudden halt, the heavy metal head keeps on moving. Its motion wedges it tightly down on the handle.

On the baseball diamond, the shortstop who spears a hard liner is often thrown over backward, because the fast-moving ball tends to keep on moving and to carry the player with it. The shortstop knows what a force was required to stop the ball; he can

tell from the blow with which the ball strikes the glove. Every base runner knows how hard it is not to overrun the second and third bases. The law of inertia of moving bodies is responsible for the rule that a player may overrun first base on a hit.

The earth and the planets never stop in their revolution around the sun because no force is exerted to stop them. So it is with the moon in its incessant circling around the earth, and with the sun itself as it carries everything with it through space at a speed of twelve miles a second. Unless some outside force is brought to bear on the heavenly bodies they will continue to spin and to revolve forever.

Did you ever ask yourself why the earth does not spin away from under you when you jump up into the air? Roughly speaking, the United States moves around from west to east with the spinning globe at a thousand miles an hour. If one jumps up from the ground, staying in the air for but a second, the ground should move under foot for a distance of about a quarter of a mile, and one should land a quarter of a mile away from the spot at which one jumped. Of course, we know that this never happens. Why? Because the jumper is moving with the earth. Even when he is in the air he moves with the earth. No force is exerted to stop that motion; and so he lands exactly where he started his jump.

The car was moving at thirty miles an hour on a smooth road and the passengers were resting comfortably on the rear seats. Then the driver saw a chance to pass the car ahead, and "stepped on the gas." The heads of the passengers were rudely snapped backward against the cushions. Their heads seemed determined to keep on moving at thirty miles an hour even though their bodies were forced to move at fifty miles an hour. A little later the driver had to jam on the brakes in order to slow up the car over a rough stretch of road. The passengers lurched forward as if wishing to continue at their former speed. In both instances they felt decidedly the force required to change the amount of motion—first from a low speed to a higher one and then from a high speed to a lower one.

In skating down a steep hill, one's speed constantly increases. This means that an outside force is constantly acting—the force of gravity. The body, tending always to remain at the lower speed, would fall backward, and so one naturally leans forward throughout the downward run.

Did you ever notice the crouching position of a ski jumper as he picks up speed down an incline? He, too, is resisting the force which is changing the rate of motion of his body.

We come now to the last of the important meanings in Newton's first law of motion. Just as the inertia of rest keeps a body at rest unless an outside force is acting, so the inertia of motion keeps the body moving at a uniform speed unless an outside force changes the amount of that speed. Furthermore, the inertia of motion carries a body uniformly forward in a straight line. The body

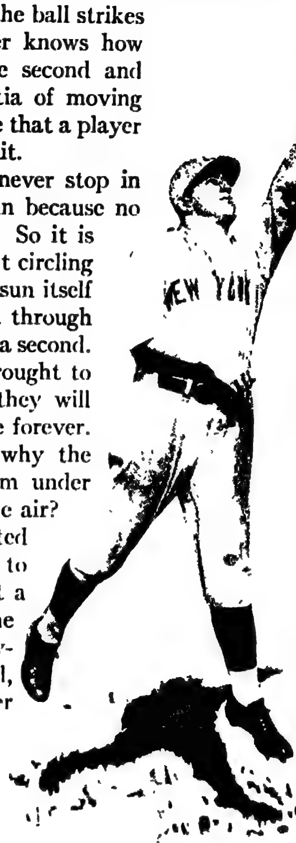


Photo by International News Photos

"Spearing a fast liner" sometimes throws a player over backward. The ball is traveling at high speed. A body in motion tends to stay in motion, and so a force is required to stop it. The strength of the impact stings the player's hand, as we all know, and if the player is out of balance, it may throw him completely.

Here are two ways of wedging the handle of a hammer into the head. One may strike the handle with another hammer. In that case the heavy head tends to stay at rest while the handle moves in. Or one may bring the handle sharply down on the table. When the handle suddenly stops, the heavy head tends to keep on going.

A body in motion in a straight line tends to continue moving in a straight line. That explains why a ski jumper soars through the air when he reaches the end of the slide on which he gets his start. Because he is moving upward when he shoots into the air, he continues to do so, even when the ground is no longer beneath his feet. Of course, the force of gravity soon brings him back to earth.

cannot change its direction unless there is an outside force to act upon it.

When a trolley car, train, or automobile travels around a curve, the passengers feel a force pulling them toward the outside of the curve. Those who stand in a crowded car moving around a bend have to grab the straps to keep from lurching sideways. The outside track around a curve on a railroad is usually banked, or raised, in order to prevent the train from flying off the track. The inertia of the moving train would keep the cars moving in a straight line. Considerable force is needed to make the train change its direction. The banked roadway resists the straight-ahead force of the train as the train rounds the curve and so helps to keep the wheels on the rails.

Why Curves Are Banked

If you have ever run around the indoor track of a gymnasium, you will recall how the floor is banked around the corners. As you run around the curves, your body assumes an angle to the main floor, though it is still perpendicular to the floor on which you happen to be at the moment, because the track is banked. Strangely enough, you do not mind being tipped over at an angle while rounding a curve, since it is easier in this position to hold to the track. Otherwise, your speed would tend to make you leave the track in the direction of the last straightaway piece of track that you were running on. Anyone who has run the bases in a ball game knows the difficulty in rounding bases at great speed. One cannot keep to the base paths; for every change in the direction of travel brings a force into play which urges your body to keep moving in the original direction.

What Is Centrifugal Force?

If the curve in a track were a completed circle, it would have a center. The force on bodies which move around the track always acts in a direction away from this center Scientists have therefore given a special name to such forces. They call them "centrifugal" (sĕn-trĭf'ū-găl) forces—which, in Latin, means forces that run away from the center. In other words, the centrifugal force results from the fact that a moving body always wants to keep ahead in a straight line, and not to round a curve.

Here is an interesting experiment which our readers may wish to try. Get a small tin can and tie it to a stout string, so that the can may be swung to and fro. The string should be about three feet long, and attached in such a way that when the can is suspended by it, the open top of the can is

Photo by Ewing Galloway, Photo Publicity N.Y. State Dept. of Commerce

The curves around a bobsled run are banked. The racers in the picture seem to be riding at a dangerous angle, but that is really the only safe way to round a curve at high speed. The embankment overcomes the force that tends to keep a sled going in a straight line right over the edge of the run.

perfectly level. Now fill the can about half full of water. Swing the can from left to right, gradually increasing the length of the swing until it is a semicircle. You may be surprised to find that even at the extreme ends of the semicircle the water does not spill. Now, increase the swing further, so that the can completes the circle. Let it go round and round. At one point in its circuit, the can is tipped upside down—and yet not a drop of water spills.

Why the Water Does Not Spill

This is an amazing fact, for it would seem that the force of gravity had ceased to act on the water. But let the can be stopped for an instant in its motion around the circle, and the water spills in the usual way if the can is upside down. Evidently, the rapid motion around the circle causes a centrifugal force to act on the can and on the water in the can. The water is being pulled away from the center of the circle. At every point in the circuit—left, right, top, or bottom—the water is being pulled hard against the bottom of the can. If the speed of rotation is sufficiently great, this pull is greater than the pull of gravity. It may be even great enough to break the string or pull it out of your hand. Should it do so, the can and water would go hurtling through the air in a direction tangent to the circle at the instant when the string breaks—that is, it would travel right ahead in a straight line from that point.

The earth and the other planets travel in curved paths around the sun. These curves, as we have learned, are ellipses, or ovals, not circles. We do not speak of the "center" of an ellipse, but rather of its "foci" (fō′sī), for it has two of them. Also, Kepler has taught us that the sun is at one of the foci of the ellipse around which the earth or any planet moves. From what we have seen of bodies

that move in curved paths, there should be a force acting on each planet tending to pull it away from the sun. This is undoubtedly so; and lucky it is for us that it should be so! Without this force, our earth would most certainly fall into the sun; as would every other planet. Also, the moon would fall into the earth, if it stopped for but a moment in its journey around the earth. Again, it is fortunate that the inertia of motion keeps the moon sailing through space around us. Perhaps it has never occurred to our readers that a struggle is constantly going on between the planets and the sun and between every planet and its moons. This struggle is between the force of gravitation and centrifugal force. Since these forces are always exactly equal and in opposite directions, the heavenly bodies of our solar system are undisturbed in their ceaseless motion in space.

Newton's First Law of Motion

From all of the foregoing our readers should be in a better position to understand the full significance of Newton's first law of motion. It is stated as follows: Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it may be compelled by an outside force to change that state.

Now the first law of motion speaks of a force which always acts when a change in the amount or direction of motion occurs. The second of Newton's laws of motion provides a means of calculating the exact amount of that force. Before we give you Newton's statement of the second law, let us try to understand its meaning.

A trolley car loaded with passengers starts up an incline. The motorman, eager to get under way, turns on the power. Suddenly there is a loud bang and a flash of electricity; the lights go out and the car stops. Although the passengers are startled, the motorman is not. He reaches up to a handle in the box where the flash and explosion took place and pushes it forward. The lights go on. Slowly he turns on the power and the car begins to creep forward. As it gains speed, the motorman shoves ahead his control another notch. He does not use full power until the car has increased its speed considerably.

What had happened? Simply this: Because the car was heavy, its inertia of rest was great. The motorman, desiring to change to a high speed too quickly, had put on full power too soon. A tremendous force was needed to overcome the great inertia. For this a large electric current was required. So large was this current that it threatened to heat up the wires and burn up the car. But in the box was a circuit breaker, which is a switch that opens automatically when the flow of current is too great. The circuit breaker snapped open with a report and a flash, shutting off the power altogether. This was a reminder to the motorman that he was asking too much of the motor. The motor could not possibly exert the force necessary to change the state of rest of so heavy a body to a state of such rapid motion. At least, it could not exert that force without burning up the car while doing so. Having been reminded, the motorman saw the evil of his ways and proceeded to speed up the car more gradually. The driver of an automobile, like the motorman, must never reach high speed too quickly; the force required to do so is too much for the engine, which promptly stalls. For this reason,

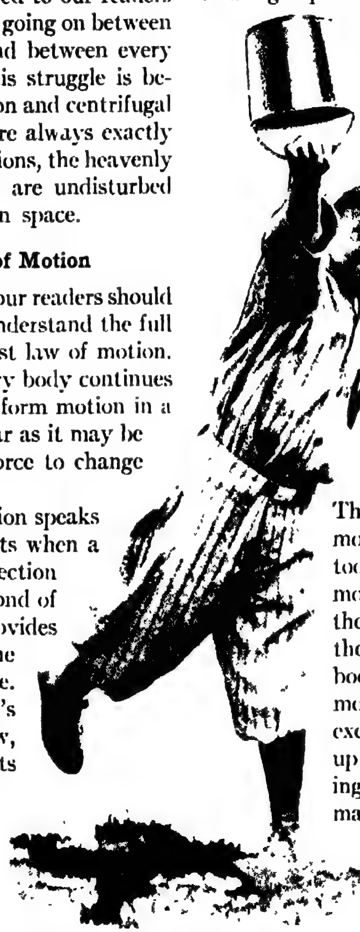


Photo by International News Photos

This ball player is teasing his thirsty team mates. He is whirling a pail full of water around his head. As you see in the picture, the pail is upside down; but not a drop of water is spilled. If his friends understood about centrifugal force, they would not worry about their water.

automobiles are equipped with transmission gears which must be set in "first speed" on starting. When the car attains some velocity, the gears are then set in "second." After an additional increase in speed, it becomes safe to put the gears in "high."

From the above we can see that the amount of change in motion determines the size of the force needed to produce the change. The more change, the more force. From rest to motion or from motion to rest; from low speed to high or from high speed to low; from motion in one direction to motion in another—each change requires a force, and the amount of the force is proportional to the amount of change.

In order to calculate any force, Newton multiplied two things. One is the mass of the body, that is, its inertia of rest. The other is the rate at which the body is changing its speed or its direction of motion. Physicists refer to the rate of change of speed as the "acceleration" (ăk-sĕl′ēr-ā′-shŭn). Hence, force is always equal to the product of mass and acceleration.

Newton's way of stating the second law of motion was as follows: Change of motion is proportional to the impressed force, and takes place in the direction in which the force acts.

Let us arrange an unusual kind of tug of war between two teams of boys. The two sides pull against each other on a rope, as is customary; but one team cannot see the other. This can be accomplished by hanging an old sheet between the two teams; the rope passes through a small hole in the center of the sheet.

If the sides are evenly matched, the rope does not move. Since victory is impossible, one team decides to play a joke on the other team. They tie their end of the rope to a tree firmly rooted in the ground and sit down to rest, while the others struggle. The result is the same as before.

Now do you think it may be said that the tree is pulling the team of boys with a force equal to their own, but in an opposite direction? Certainly, it is acting as an equivalent substitute for the team that is resting. Newton believed that when a tree is pulled, the tree pulls with equal force in the opposite direction; when it is pushed, it pushes back with equal force.

Try jumping off a chair. As you jump away, the chair flies back. Why? Because in jumping forward you give an equal and opposite push to the chair. The same effect occurs when a gun is fired. As the bullet leaves the barrel, the stock of the gun is forced backward against your shoulder. When cannon are fired, recoil springs are provided so that the backward shove of the shell as it leaves the muzzle may not smash the cannon and its mounting.

Newton stated his third law of motion as follows: To every action there is always an equal and opposite reaction.

This daring bicycle rider is going to "loop the loop" on his narrow track. But to do so without falling to earth he must get up tremendous speed.

If our rider is going ahead at high enough speed, centrifugal force will overcome the force of gravity and he will not fall from the track.

Reading Unit No. 6

WHAT MAKES A MOVING THING STOP?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Perpetual motion, man's permanent folly, 1–315-17
The Redheffer hoax, 1–315-16, 318
What is friction? 1–318
What prevents many bodies from moving? 1-318
Where may perpetual motion be possible? 1–319
What makes writing possible? 1–319
How can friction be reduced? 1-320-21
How is friction increased? 1–320-21

Things to Think About

Why do roller-skate wheels spin easily?
Why are machines oiled?
Why would raindrops hit us like bullets if there were no friction?
When do we need friction?

Picture Hunt

Why are these perpetual-motion machines impracticable? 1–317
How does the automobile clutch operate? 1-318

Related Material

How may friction produce heat? 1-320
How is the power of the automobile engine transmitted to the rear end? 1–318, 331, 10–282-91
Why do tires hold to the ground? 9–270
How do railroad brakes work? 10–196
How is friction applied in stopping the motion of an automobile? 10-291
How is air pressure used to apply brakes? 1-461-62, 10-196
Why do bearings burn out? 1-320
How do ball bearings reduce friction? 1-319

Leisure-time Activities

PROJECT NO. 1: Construct models of so-called perpetual-motion machines in order to show the impossibility of perpetual motion, 1–317.

PROJECT NO. 2: Collect pictures, charts, drawings, and samples of bearings of various types, 1-319, 320, 321.

Summary Statement

Friction is the resistance which must be overcome in moving one object past another. Friction can both help and hinder us in our various activities.

Little Coleman Sellers is looking into the room where Redheffer's famous perpetual-motion machine is being exhibited. It was this boy's fine observation which showed the machine to be a fraud.

WHAT MAKES A MOVING THING STOP?

If You Start a Ball Rolling, It Will Finally Come to Rest. Do You Know Why?

"FATHER, I have invented a perpetual motion!" said a little fellow of eight years old. And this is how the child explained the invention, as the story is told in Phin's book, "The Seven Follies of Science": "I would make a great wheel, and fix it up like a water wheel; at the top I would hang a great weight, and at the bottom I would hang a number of little weights; then the great weight would turn the wheel half round and sink to the bottom, because it is so heavy; and when the little weights reach the top they would sink down, because they are so many; and thus the wheel would turn round forever."

Ever since man became interested in moving things he has been puzzled, and sometimes annoyed, over the fact that he could not make a machine that would run forever without any additional effort on his part. We may laugh at the ridiculous notion of the boy, quoted above, and pardon him because of his years. Yet grown men, clever men, and well-educated men have until recently devoted many years of their lives to working out some device that would fulfill this child's dream of perpetual motion. Is it not singular that in a world where everything moves, where matter in its ceaseless round is constantly being urged by forces to move, where even the heavenly bodies never stop their spinning nor their revolving, man alone should find himself baffled in the attempt to make matter move forever?

We shall soon see that there is a good reason for this failure, and that the very laws which control the ceaseless motion of the universe make man's ambition a futile one. But ambitions are powerful things and do not die easily. To this day the United States Patent Office receives applications for patents on perpetual-motion machines. The applications are all rejected with the statement that such machines are believed to be contrary to the accepted laws of science. A century ago, however, the government was less certain, and gave care-

Curling is a game played only on wide expanses of glassy ice, where there is little friction. A player throws his "stone" and then uses the broom to clear away fine ice particles in front of it or to sweep them in its way and so slow it down. The game is popular in Canada and in Switzerland.

ful consideration to numerous ideas and actual models based upon these ideas.

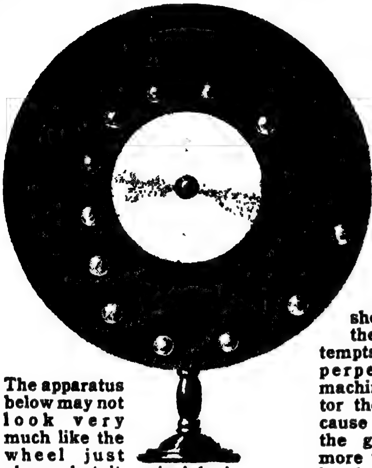
One such model created great excitement in Philadelphia, in the year 1812. A certain Charles Redheffer had built a machine which he said could run forever. He proved it by putting the machine on exhibition. People flocked from everywhere to see it. Apparently Redheffer had succeeded, for the machine kept running day after day, week after week, month after month. So great was the excitement that the Pennsylvania legislature appointed a commission of eminent engineers to investigate the truth.

The Hoax Uncovered

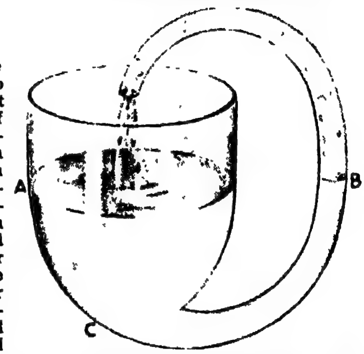
The commission arrived at the exhibit, having first notified Redheffer of their coming. But the house was locked and the key missing. Through a barred window they caught sight of the machine. It was turning. They saw a vertical shaft carrying a horizontal disk. On the disk were two inclined planes, and upon these, two weights descended and rose as the disk revolved. The disk had teeth on its outer circumference; these engaged teeth in a smaller gear, and the small gear moved other mechanisms. It seemed as if the falling weights were responsible for the turning; and the weights never ceased to fall, to rise, and to fall again.

One of the commissioners had brought his son with him. The boy's name was Coleman Sellers. Like most boys he loved to play with toys that moved. Coleman looked long and hard at the disk and its toothed gears. He noticed something which the wise men of the commission, including his father, failed to see. He noticed that one side of every metal tooth was worn smooth and shiny by the long-continued motion of the disk. Now that was not remarkable. It was to be expected, in fact. But Coleman noticed that each tooth was worn *on the wrong side*. If the disk moved the smaller gear, then one side of each tooth should show wear; but if the small gear moved the disk, then the *other* side of each tooth should show the effect. It looked as if the disk was being moved by some outside force, and not as if the disk was doing the moving.

When Mr. Sellers returned from the inspection, Coleman told him what he had noticed. Thereupon the boy and the father had a small model made which duplicated exactly the Redheffer machine. It was moved by clockwork, and the springs were



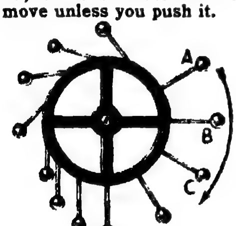
For centuries man has tried to invent a perpetual-motion machine—that is, a machine that would run forever without any outside energy or "push." He has wanted a clock that need never be wound, a wheel that would never stop spinning, or a fountain that would play forever without an outside supply of water. Such machines would be of little use to us, for they would stop the minute we tried to use them as a source of power. But they would satisfy man's longing to overcome Nature's habit of stopping moving things.

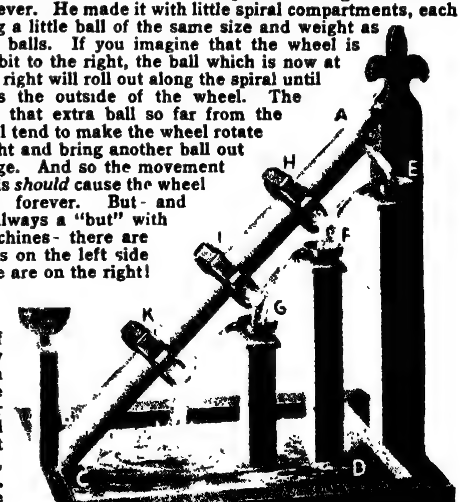


The simple apparatus to the right shows you one of the earliest attempts to make a perpetual-motion machine. The inventor thought that because the water in the goblet weighed more than the water in the tube B, the main mass of water would force the water in the tube up and around until it fell back into the goblet again. If this action could take place, the water would continue to flow round and round for a time limited only by the strength of the glass. The "catch" in this scheme lies in the fact that the greater part of the weight of the water in the goblet is held up by the sloping sides of the glass. The weight that is not supported in this way is exactly balanced by the weight of the water in the tube.

Another would-be inventor of a perpetual-motion machine made the wheel above to the left. He expected it to go round and round forever. He made it with little spiral compartments, each containing a little ball of the same size and weight as the other balls. If you imagine that the wheel is turned a bit to the right, the ball which is now at the upper right will roll out along the spiral until it reaches the outside of the wheel. The weight of that extra ball so far from the center will tend to make the wheel rotate to the right and bring another ball out to the edge. And so the movement of the balls *should* cause the wheel to rotate forever. But—and there is always a "but" with these machines—there are more balls on the left side than there are on the right!

The apparatus below may not look very much like the wheel just above, but its principle is exactly the same. It is made of a wheel to which balls on little rods are attached by a hingelike arrangement. The hinge will allow the rod to fall to the left, but to the right they fall only as far as positions A, B, and C. The inventor hoped that the weight of the balls that fall to the right would be enough to pull the wheel around and make other balls fall and pull and so keep the wheel moving indefinitely. But, just as in the wheel above, there will be more balls on the left than on the right, the weight will be evenly balanced, and the wheel will not move unless you push it.





The machine to the right is run by a series of three little water wheels driven by three tiny "Niagaras." Inside the long tube there is a screw like the one below the machine. If we turn the screw to set the machine going, water will be forced up to the top of the tube and will flow out into the tiny basin E. From here it falls to basins F and G in little waterfalls, pushing around the little paddle wheels H, I, and K. These wheels are attached to the screw so that, once set in motion, the falling water should turn the screw and raise more water to fall—and so on forever. *But* there is friction in the bearings of the screw and in the water itself; so the machine will soon come to rest.

cleverly concealed in one of the supporting posts They invited Redheffer himself to see their model and even he was mystified. Knowing his own guilt, he was frightened. He wondered if the Sellers had actually discovered the secret which he pretended to have discovered. He offered young Coleman a share in the profits to be made from the invention. Needless to say, the boy only laughed; but he told no one of the trick that had been played upon Redheffer.

The next year Redheffer's perpetual-motion machine was exhibited in New York, where thousands came to see it, paying a dollar per person for the privilege. Robert Fulton, the man who invented the steamboat, was one of the many who were attracted to the show. He laughed when he saw the machine, and did not hesitate to denounce Redheffer as a fraud. He told the crowd which had gathered that he was ready to *prove* the whole thing a cheat. He volunteered to pay any penalty if he failed, but asked for support from the group in making the attempt.

When this was granted he began to tear away certain thin strips of wood which Redheffer said were merely to steady the machine. The strips reached to a wall of the room. Upon removing the wood, Fulton uncovered a string that passed through the wall and up to a loft at the rear of the house. They all rushed to this loft. Finding it locked, they broke in. There they found an old, bearded man sitting on a box. In one hand the man held a dry crust of bread which he was slowly munching; with the other hand he was turning a crank. The crank moved the string and the string moved the so-called perpetual-motion machine.

The clutch in an automobile depends for its action upon the force of friction. After shifting gears with the clutch disengaged, as shown in the upper diagram, the driver lets in the clutch. A series of discs then come in contact with each other, as shown in the lower diagram. It is just as if a number of coins were to be pressed together after the fashion shown in the circle. It is then difficult to turn one coin without turning them all.

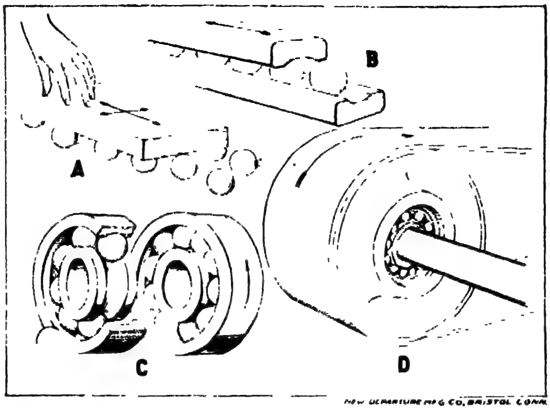
In earlier chapters we learned about the force of gravitation—a force which exists everywhere in space and which is ever acting. In this chapter we shall read about another great force—the force of friction which acts only where matter is to be found and only when one object rubs against another.

It takes force to rub one body over another. As we rub we overcome a resistance which is called friction. Sometimes the resistance of friction is so great that one body will not move over another at all. Always the force of friction slows up the movement of bodies. That is why Redheffer's machine needed the old man to turn a crank; and that is why the model made by Coleman Sellers needed a clock spring. The old man and the clock spring provided an outside force with which to overcome the force of friction.

Perhaps you recall, from one of our earlier articles, the experiment which Fred's uncle performed to show why a piece of paper does not fall so fast as a piece of metal. You may remember that the air rubbed more, proportionately, upon the

paper than upon the metal. When Fred's uncle got rid of the air, the two objects fell at the same rate of speed. The frictional resistance of the air, therefore, causes light objects to fall more slowly than heavy ones. A parachute settles slowly to the ground when it opens; for only then can it present a large surface to be rubbed by the air. The life of many an aviator has been saved by the force of friction.

Why do not the earth, the planets, the moon, the sun, slow up in their travel through space? Because they move through space that is empty of all matter. No force of friction can resist their movement because there is no air—there is nothing—against which the surfaces of heavenly bodies may rub. In a sense, therefore, perpetual motion *is* possible among bodies in empty space. On the earth, where man carries on his existence, perpetual motion is made impossible by friction.



If a book or piece of board is placed upon a number of glass marbles, as shown at A, the book can be moved in any direction by the lightest touch. Now if two pieces of wood with grooves cut in them are put together with marbles in the grooves, as shown at B, the top piece of wood can be moved backward and forward very easily—but not to the side, because of the grooves. Now suppose that these two pieces of wood were bent until they became two rings—one larger than the other—with the balls between them in the grooves, as shown in picture C. Then it would be possible to put one's fingers through the hole in the small ring, so as to hold the ring still, and then spin the larger ring around and around, since the larger ring would roll on the balls. That is the principle upon which ball bearings work. The picture marked D shows a ball bearing in a pulley. The shaft, which does not turn, is fitted into the hole in the bearing. The pulley has a hole in it which fits tightly over the outside of the large ring. Therefore the pulley may be turned very fast because it is rolling on perfect steel balls which roll around and around in the grooved rings of the bearing.

Did you ever try to write with chalk on a windowpane? The trouble is that the glass is too smooth. Not enough friction resists the movement of the chalk; and so the chalk does not wear away and leave its mark on the glass. As a matter of fact, friction makes all writing possible, whether it be with chalk on a blackboard, with pencil on paper, or with pen and ink.

If roller skating on a hardwood floor is easier than skating on a carpet, it is because the rougher surface of the carpet causes greater friction. Polishing furniture is less tiring than scrubbing floors, since less force is needed to overcome the friction between an oiled

These men could not possibly drag the heavy slab of stone over the rough ground. The friction would be too great. By inserting the cylindrical rollers, they have changed "sliding" friction into "rolling" friction. A cylinder is the next best thing to a sphere for use when friction is to be reduced.

rag and a smooth table top than to overcome the friction between a rough brush and a scratched floor.

When a carpenter finishes a chair he proceeds to make it smooth; for people must sit in it. If the seat is rough, not only does it prove uncomfortable, but it results in much friction against clothing and causes unnecessary wear and tear. In order to smooth the chair, the carpenter first uses coarse sandpaper, then paper that is less coarse. Then he fills every pore with a special "wood filler" and polishes the surface smooth. After staining and varnishing it, he may rub it again with wax, so as to produce a surface against which the friction of rubbing will be as small as possible.

Every motorist knows that a concrete road is easier to travel on than a dirt road. The "detour" sign is always an unwelcome sight, for the driver knows that a rough roadway awaits him, with much friction between wheels and road. Both his comfort and his tires are destroyed. But the same driver is glad enough to increase the friction between tires and road if the latter is wet or icy. He then roughens the wheels by incasing them in chains.

Why Oil Reduces Friction

Why does oil reduce the friction between rubbing surfaces? Chiefly because it makes the rubbing surfaces smoother. Even though wheel axles and revolving shafts are polished smooth in the factory, their surfaces contain minute pits and cavities which no amount of polishing will remove. The oil fills these holes and irregularities and forms a smooth film which keeps the rough surfaces from rubbing against each other.

One needs more strength to drag a heavy log than a light one. Pressing hard on the brake pedal stops a car sooner than pressing lightly. Shifting the position of a piano is harder on the carpet than shifting the piano stool. The emergency brake is more reliable than the foot brake because it presses harder on the wheel rims. More vigorous strokes of the toothbrush produce cleaner teeth. Dirty clothes require harder scrubbing than slightly soiled ones. Heavy persons wear out their shoes faster if they are as active as their lighter friends. Trucks wear out the roads faster than do automobiles. And steel trains must ride on steel rails.

In every instance cited above, and in the many other similar ones which may come to mind, the amount of friction resisting the motion of one object over another depends upon the force with which the two are pressed together.

More Causes of Friction

The motorist or train engineer who forgets to oil all rubbing surfaces in his engine is soon stopped by burnt-out bearings; for friction produces heat. The friction in rubbing one hand over another helps to make our hands warm, as we all know.

It may well be said that hardly an act of our lives is performed without encountering the resistance of friction. As we overcome friction we generate heat. Walking warms the body, the sidewalk, and the air around both. Boring a hole through wood makes the drill too hot to touch. Grinding a knife sends out sparks of heated steel and stone. Riding a bicycle or roller skates makes the wheel bearings so hot that we resort to oiling in order to reduce friction Boys sliding down a banister or a rope often scorch their hands. Many a train has caught fire because a loose "brake shoe" becomes heated through friction. And the shooting stars we watch for on a clear summer night are really pieces of stone and iron heated to incandescence by friction.

How the World Moves on Wheels

We often hear the expression, "The whole world moves on wheels"; and many have said that the wheel is the most important and most valuable of all of man's inventions. No one knows who it was who invented the wheel, or when. It must have been in the dim past that a huntsman, more intelligent than his fellows, found an easy way of bringing home his catch. Whereas his companions threw the dead animal upon their shoulders or dragged it along on the ground, this man placed the carcass on smooth round poles and pulled the poles along as he walked. Later, perhaps, he dis-

covered that placing the poles in position so that they rolled along, made the task even easier. Later still, with the aid of other experimenters, this huntsman fashioned two round slabs of wood, connecting their centers with what amounted to an axle—and a crude wagon for hauling heavy objects was the result.

Whatever was the process by which man first learned the advantages of rolling friction, wheels have certainly become our chief means of reducing the force of friction. All transportation on land depends upon wheels, and practically every machine uses the principle of the wheel. Even the steamship and the airplane make use of wheels in the engines which drive them.

The other day we heard a boy say, "Father, will you buy me a pair of ball-bearing skates? The ones I have do not ride well at all. Besides, I am just as good as the new piano, and even that has ball-bearing casters." Whether the boy understood it or not, he knew from experience that rolling friction is less than sliding friction.

Thus far we have described, in the main, the disadvantages of friction to mankind. It has seemed to be a great hindrance to motion. It has been a force to be overcome if possible. But friction has its uses The best way to appreciate the values of friction is to try to imagine a world in which it does not exist. In such a world, walking would be impossible. Even standing would be difficult for man. At every step he would slip and fall. Bear in mind how gingerly one walks on ice or on a highly polished floor.

Then, too, writing would be practically impossible; chalk and pencils would be useless, and therefore unknown. As for vehicles, it is difficult to see how they could ride. Every wheel would spin round without moving forward, just as they do when a car is stuck in the mud. If we did manage to start a car or a train, it would skid terribly at the slightest turn in the road. Putting on the brakes would be meaningless, because brakes depend entirely upon friction.

The violin as a type of musical instrument would not exist in a world without friction, since the sound produced by bowing a string is due to vibrations started by the force of friction. Perhaps you have noticed how a violinist rubs rosin on the bow before playing. The purpose of this is to increase the force of friction. Without friction, polishing, cleaning, scrubbing, and sand blasting would be effort wasted.

The most annoying thing would be that no object could ever be placed exactly where one wanted to place it. One might try to set a glass carefully on the table; but the slightest push as the hand was released would start the glass moving. And since there was no friction, your glass would move forever, bumping its way around from place to place.

We must not forget to add that in a world without friction it would be dangerous to be out in a rain. Every raindrop would strike with the speed of a bullet. And the same danger would await us in the form of meteorities, for thousands of these bits of metal from the skies fall toward the earth every hour. As we said before, friction causes these missiles from space to get so hot that they burn up in the air. Finally, a frictionless world would have no sandy seashores, and probably no top soil. Without soil plant life would cease to exist, and without plants there could be no animal life of any kind.

What a dreary place the world would be!

This skater can speed over the ice because friction has been reduced to a minimum.

Metal skates are better than wooden ones because the wood offers greater friction.

PHYSICS

Reading Unit
No. 7

THE REAL SECRETS IN MACHINERY

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What forces must be overcome in moving an object? 1-323
Why is our age called the Age of Machines? 1-323-24
What is the simplest machine? 1-324
What are the essential parts of a lever? 1-324
Classes of levers, 1-327-28
The biceps as a lever, 1-327-28
How may a heavy piano be lifted by one man? 1-328-30
Why are gears a development of the wheel and axle? 1-331

Things to Think About

What makes an automobile easy to steer?
How may a small weight be made to move a heavier weight?
How does a crowbar help a man to lift a heavy stone?
How are weights and distance related in moving objects by means of levers?

Picture Hunt

What are the different classes of levers? 1-324
What are examples of different uses of the lever? 1-325-27

Related Material

When did the modern Machine Age begin? 6-84, 10-529-37
Why must machinery be oiled? 1-382
How is the principle of the lever applied in the automobile transmission? 1-331
How is a seesaw an example of a lever? 1-324, 327
How do derricks work? 9-253
How do gears make it possible for automobiles to operate? 10-289
How does the modern elevator operate? 1-337
How do muscles do work? 2-329-31

Practical Applications

How are machines used in construction? 1-324-31
What simple devices found in the home operate on the principle of the lever? 1-324-31

Leisure-time Activities

PROJECT NO. 1: Make a seesaw, 14-42.
PROJECT NO. 2: Show four of your friends that you can beat them at a tug of war, 1-328

Summary Statement

The complex machines of today are elaborations of simple machines.

In order to roll this stone uphill, one must counteract the force of gravity and the force of friction. Inertia, too, must be overcome. Early man depended entirely upon his own muscles for such work. To-day we use machines; for they accomplish with ease tasks for which our bodies are not fitted.

The REAL SECRETS *in* MACHINERY

Here Are Half a Dozen Prime Inventions That Underlie Most of the Vast Machines in Our Modern World

FROM the very dawn of time man has had to wage a constant battle with wild beasts, with men, with hunger and heat and cold, with tempests, and with disease. But his greatest battle of all has been with forces. In order to lift and to climb he has had to overcome the force of gravity. When he sought to make a stationary object move or to stop one that was moving, he was compelled to overcome inertia. Every time he rubbed one body against another, much of his effort was spent in overcoming friction. In time, he learned how to resist these forces and how to make use of them. To live intelligently was to get as much help and as little hindrance as possible from the forces which were everywhere about him.

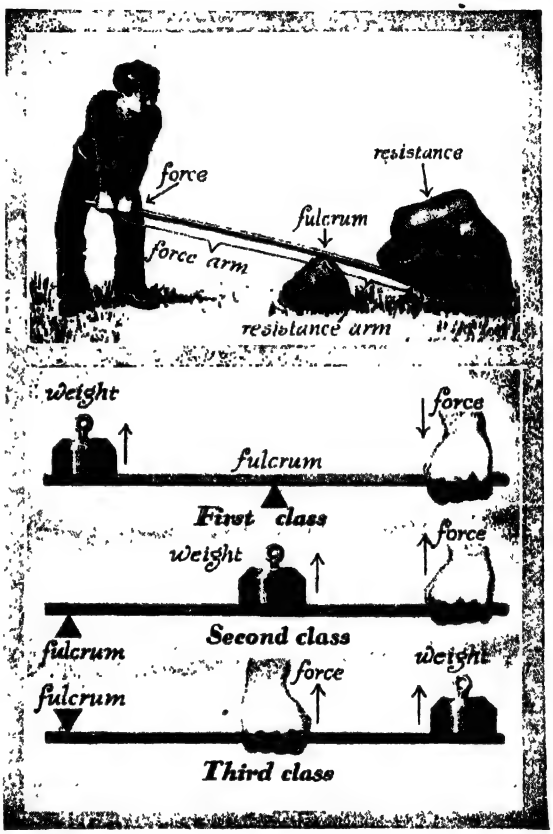
In the beginning, man used only his body. In his struggle against inertia and friction and gravity he could bring only his muscles to bear. Frequently dangers surrounded him; to meet them he often needed forces so great that his body alone could not possibly furnish them. When his muscles failed him, he suffered inconvenience, injury, and death.

But man survived. He outlived many other forms of life and overcame many conditions which threatened his existence, for he possessed a mind as well as a body. Exercising this mind, he soon learned how to change his own puny force into a larger one. He learned, too, how the effect of large forces may be reduced. In short, he invented machines!

We must not think that machines came into existence quickly or easily. There are records of men on earth six thousand years ago. Yet the pyramids, erected some five thousand years ago, were put up chiefly by means of bone and muscle. The machines used in their construction were of the very crudest kind. In the years which followed

the building of the pyramids machines were improved very little. The Greeks and the Romans, who came later, did not add much to man's knowledge of how to control forces with machines. For any real advance we must wait for the years which followed Galileo and Newton, in the eighteenth century. And the machines which built the Empire State Building were invented only within the last hundred years or thereabout.

To-day we live in a machine age, in which most of the world's work is done by machines. We no longer rely upon our muscles to overcome inertia, friction, and gravity. We know thousands of ways by which our bodily strength may be magnified and multiplied. We may even save our strength entirely, and call upon other forces to do the work of making life safe, comfortable, and convenient.



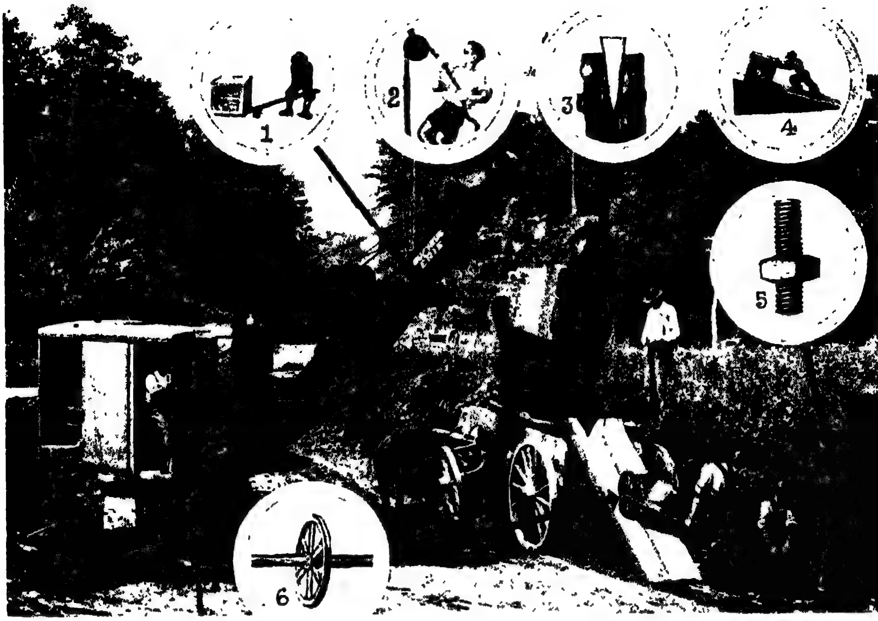
As the boy lets his weight push downward upon one end of the steel crowbar, the heavy stone moves upward. The boy weighs less than the stone; without the lever his muscles could not even budge the stone. Notice that in the first and second classes of lever, the "force arm" is longer than the "resistance arm." In the lever of the third class, the "force arm" is shorter; therefore it cannot be used to magnify the applied force. The boy, as you will notice, is using a lever of the type shown immediately below him.

In order to unstand and appreciate such complicated machines as derricks, steam shovels, locomotives, and automobiles, we must begin with a study of machines that are simple. The complex machines, like the simple ones, magnify or diminish forces, resist or overcome them, and they are built upon the same principles as the simpler ones. The very simplest of all machines is the lever.

If you have ever been on a seesaw, you know what a lever is like. When you are up and your companion is down, the force of gravity soon begins to pull you down. As you go down, you are lifting your companion, so that your weight is overcoming the resistance caused by the pull of gravity upon him. Thus, your motion downward is rather slow—much slower than it would be if you fell headlong from the same height When your companion goes down, the situation is reversed. In both cases, a force applied at one end of the seesaw overcomes a resistance at the other end. That is why a seesaw is a lever.

In explaining how levers of different kinds operate, it will help us if we learn the name given to each important part of a lever. First, is the "applied force"; second, the "resistance" overcome; third, the "fulcrum," which is the point at which the lever is pivoted. The distance between "applied force" and "fulcrum" is called the "force arm," and the distance between "resistance" and "fulcrum" is called the "resistance arm."

Let us return to the seesaw. Should your companion be somewhat lighter than you, the only simple way of keeping up the fun is for you to move closer to the fulcrum. If he happens to be heavier, then *he* must move



Four men and two horses are at work on a job of excavation. Neither the men nor the animals seem to be overworked. It would take a whole army of hard-working men and mules to do this job without machines. As it is, the principles of the following devices have been applied in various machines—as indicated by the arrows: 1, lever. 2, fixed pulley. 3, wedge. 4, inclined plane. 5, screw. 6, wheel and axle.

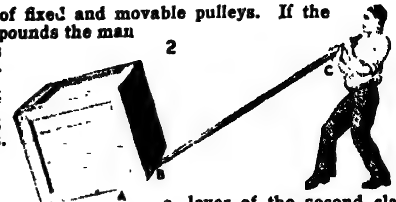
closer to it. Evidently, the distance of the applied force from the fulcrum controls the effect of the force upon the resistance. Similarly, the length of the resistance arm determines the size of the force which must be applied to overcome the resistance. From this it is clear that the lever provides a method for overcoming a large force by the exertion of a smaller one.

How the Lever Works

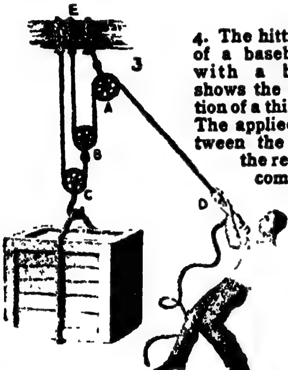
A laborer uses a lever in this way when he pushes the point of a crowbar under a boulder, inserts a small stone under the crowbar, and leans his weight down against the very end of the bar. As he moves down, the boulder, much heavier than his body, moves up. Another example of a lever of this kind in action is a claw hammer drawing a nail from a board. In this case, the head of the hammer, which is braced against the board, is the fulcrum. The nail, held by friction, is the resistance to be overcome. The muscles of the arm pulling at the end of the hammer handle apply the force. Still other examples of the working of levers are a pair of scissors cutting through cloth, a pump handle worked up and down, and beam-balance weighing scales.

In studying the action of a lever there is one very important fact to remember. It is that the small applied force always moves through a larger distance than does the large resistance which it overcomes. Thus, if you are the heavier partner on a seesaw and must, therefore, sit in closer to the fulcrum, you find that you do not go up so high or travel down so far as does your lighter companion. *He*, probably, has the more fun. Also, in the case of the the laborer using a crowbar on a boulder, the man finds himself moving down with the handle for a distance of perhaps two feet while the boulder rises only an inch. In the same way, when you draw a nail with a claw hammer, your hand tugs through a distance of several inches in order to pull the

1, lever of the first class. The fulcrum, B, is between the force applied, C, and the resistance overcome, A. The man pushes downward to raise the box. The smaller the distance AB as compared with the distance BC, the easier is the man's task.



2, lever of the second class. The fulcrum is at A, where the end of the steel crowbar touches the ground. The man pushes upward in order to raise the heavy box. Here the distance AB must be small in comparison with the distance AC.



3, combination of fixed and movable pulleys. If the box weighs 100 pounds the man needs to exert a force of only 25 pounds.

4. The hitting of a baseball with a bat shows the action of a third-class lever. The applied force is between the fulcrum and the resistance overcome, or the ball.

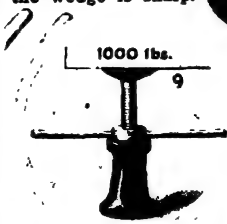
5. The man could not lift the heavy box to the platform; but he *can* slide it up the inclined plane.

The more gradual the incline is, the easier is the task. If we divide the length of the inclined plane by the vertical height, we get a measure of the ease with which any inclined plane can help us to raise weights.

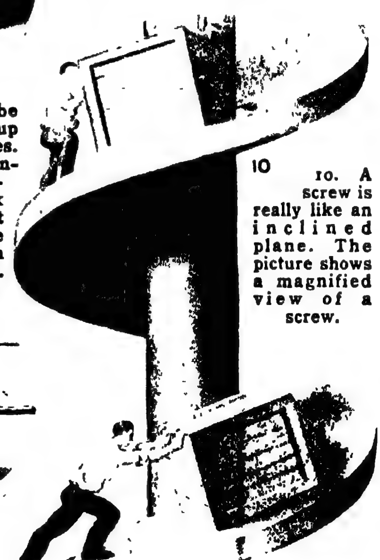
6. A wedge may be considered as made up of two inclined planes. If the length of the incline is great compared with the thick end of the wedge, it is easy to drive the wedge in; for then the wedge is sharp.

7. There are two ways of explaining why this man puts rollers under his box. We may say that when a body is rolled there is less friction to be overcome than when it is slid. Or we may regard the rollers as wheels and axles with the pressure applied to the outer rim.

8. The wheel and axle is really like a lever. The lever which the man is turning may be regarded as two spokes of a wheel. The twisted rope is the axle. The longer the stick, the larger the wheel, and the easier it is to drag the box.



9, the jack screw. One complete twist of the lever raises the 1000-pound weight a distance equal to the thickness of the thread plus the thickness of the groove.



10. A screw is really like an inclined plane. The picture shows a magnified view of a screw.

nail out half an inch. In the beam balance, however, the arms are exactly equal; so the applied force and the resistance overcome are also exactly equal. This must be so, of course, if the balance is to weigh things accurately. Five pounds of sugar on one pan must exactly balance the five-pound weight placed on the other pan.

If you have followed closely the above paragraphs, you will understand the four important uses of all levers, namely:

1. To change small forces into larger ones.
2. To change large forces into smaller ones.
3. To change a small amount of motion into a larger amount.
4. To change a large amount of motion into a smaller amount.

Here are three simple tools which illustrate the three classes of levers. The pliers belong to the first class because the "fulcrum" is between the "force" and the "resistance." The nutcracker belongs to the second class because the "resistance" is between the "fulcrum" and the "force." The shears belong to the third class because the "force" is between the "fulcrum" and the "resistance."

Some of our readers may like to work with figures and to do arithmetical problems. They will be interested in the law of the lever, which says that in all levers, the "force" multiplied by the "force arm" is always equal to the "resistance" multiplied by the "resistance arm." For example, a boy weighing 75 pounds balances a seesaw with a man weighing 150 pounds. The boy sits 6 feet away from the fulcrum. How far away from the fulcrum does the man sit? The answer is that the man must sit 3 feet away, since 75 times 6 is exactly equal to 150 times 3. And more than that, the boy moves up and down through a distance which is twice as great as the distance through which the man moves; for his weight is half as great.

Figure This One Out

Can you calculate the answer to this problem? A man weighing 150 pounds balances a seesaw with a child weighing 50 pounds. How far down does the child move when the man goes up one foot?

All of the examples of levers which we have been talking about are known as levers of the first class. In this kind of lever, the fulcrum is always somewhere between the force and the resistance. But the fulcrum in a lever may be at one end, with the force at the other end. Such a lever is called a lever of the second class.

A Few Levers of the Second Class

Let us examine a nutcracker in action. The pivot or hinge is the fulcrum; and it is at one end. The hand, which is the applied force, is at the opposite end. The resistance to be overcome – the nut to be cracked—is somewhere in between. So a nutcracker is a lever of the second class.

There are many other examples of such levers, among which we may mention the wheelbarrow, the oars in a rowboat, the lemon squeezer, the safety valve in a steam boiler, the hole puncher, and the can opener. Even a crowbar may be used as a lever of the second class when the point is inserted under a stone and the upper end pushed forward. When used in this way the point of the crowbar, which is the fulcrum, is at one extreme end of the lever, while the force is applied at the other extreme end.

In certain kinds of levers the fulcrum and the resistance are at the extreme ends, while the force is applied at a point somewhere between the two. Such a lever is known as a lever of the third class. A fishing rod is an excellent example of a lever of this type. The rod usually rests against the body or is held in one hand close to the chest. This end is the fulcrum. At the opposite end is the fish, frantically tugging at the rope. The force is applied by the fisherman's other hand at a point part way up the rod. Among the many third-class levers which are used in everyday life, the following may be listed: the derrick boom, the spring mousetrap, the sugar tongs, a pair of tweezers, the grass

shears, and the fire tongs. One of the finest examples of third-class levers is the biceps muscle of the human arm. Examine your own carefully, as you use it to raise a book held on the palm of your hand. The arm is hinged at the shoulder, which is the fulcrum. The weight of the book is the resistance to be overcome. Thus, fulcrum and resistance are at the extreme ends of the lever. The force, applied by the biceps muscle acts, of course, at a point between the two ends.

The Use of Third-Class Levers

An interesting fact to be noted about nearly all levers of the third class is that they are used chiefly to produce a large amount of movement on the part of the resistance. The force applied is therefore greater than the resistance overcome, and moves through a distance which is shorter. You might see if this is not true in each of the examples of third-class levers that we have just described.

Some time ago the writer witnessed a strange tug of war—strange for two reasons: first, because one small boy pitted his strength against four larger ones; and second, because of the astonishing outcome of the match. For the small boy won. This is how it happened:

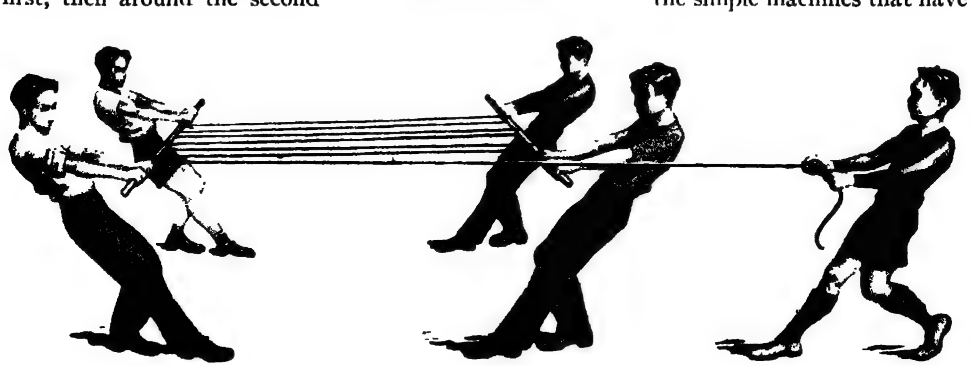
One end of the rope was tied to a smooth broomstick, held horizontally by Jim and Robert. Frank and Sam held a similar stick and stood facing their two team mates. The rope was looped around the second stick, then around the first, then around the second again, then around the first once more, then around the second stick a third time and around the first stick a third time. The loose end was held by little Henry, who was the sole opponent against the four huskies. It was his aim to pull hard on his end of the rope, so as to bring the two sticks together and make his opponents' hands touch. They, on the other hand, were to pull the sticks as far apart as possible, in an effort to pull the rope out of Henry's hands or pull him off his feet.

"Ready, go!" yelled the referee. Jim, Robert, Frank, and Sam dug in their heels and pulled for all they were worth. Strangely enough, Henry held his own against them, without overexerting himself. Then Henry gave a yank, and the rope began to slip around the sticks. At the same time, the sticks drew closer together. Frantically the four boys redoubled their efforts; but try as they would, they could not keep the sticks from approaching each other. Finally, with a last jerk, Henry brought the two sticks together, squeezing his opponents' knuckles somewhat painfully, it must be admitted.

When asked to explain how the victory was won, Henry, who had learned something about levers, replied, "Why, it was simple. I was at the proper end of a pulley. It was just as easy for me to out-pull them as it is for a man to hoist a heavy piano. The more often the rope is wrapped around the sticks, the easier it is for anyone to bring the sticks together."

The pulley is the second of the simple machines that have

This picture shows how Henry won a tug of war against Jim, Robert, Frank, and Sam. As a matter of fact, Henry did not have to pull very hard, since the stick-and-rope arrangement multiplied Henry's pull six times. If you will count the number of strands of rope passing around the sticks, you will find that there are exactly six, not counting the one in Henry's hands. Every time Henry pulls out six feet of rope, the other boys come a foot closer to each other.



become very useful to man. Pulleys are of two kinds: fixed and movable. Each kind has its special purpose.

The fixed pulley is useful, first and last, as a matter of convenience. It does not magnify the force applied to it and, therefore, does not change the amount of motion caused by it. What it does change is the direction of the applied force. One pulls *down* on the rope in order to *raise* the flag. The fixed pulley makes this possible. The same thing is true of a clothesline. The rope passes around two fixed pulleys, and with such an arrangement, one pulls the cord *toward* oneself, in order to send the washing *away*. Also, every window frame that moves up and down is attached to sash weights at each side. When the sash weights go *down*, the window goes *up*. This is because the cords which tie the weights to the window frame pass over fixed pulleys. The fixed pulleys change the direction of the applied force. All these devices add greatly to the convenience of daily living.

This piano mover is a lazy fellow. He lets the force of gravity pull him down, and so raises the piano. Since there are six strands attached to the movable pulley, each time the man falls clear to the ground, the piano is raised one-sixth of the distance. It takes six trips from window to ground to raise the piano to the window.

Henry won the tug of war because he made use of the principle of the movable pulley. In order to understand this idea, let us consider a 100-pound weight hanging from a single movable pulley. The rope is tied to a beam at the top, passes around the pulley, and then up and around another pulley fixed to the beam. One takes the end of the rope and pulls. Apparently, it needs only a 50-pound pull to lift the 100-pound weight. Now why?

Why Henry Won the Contest

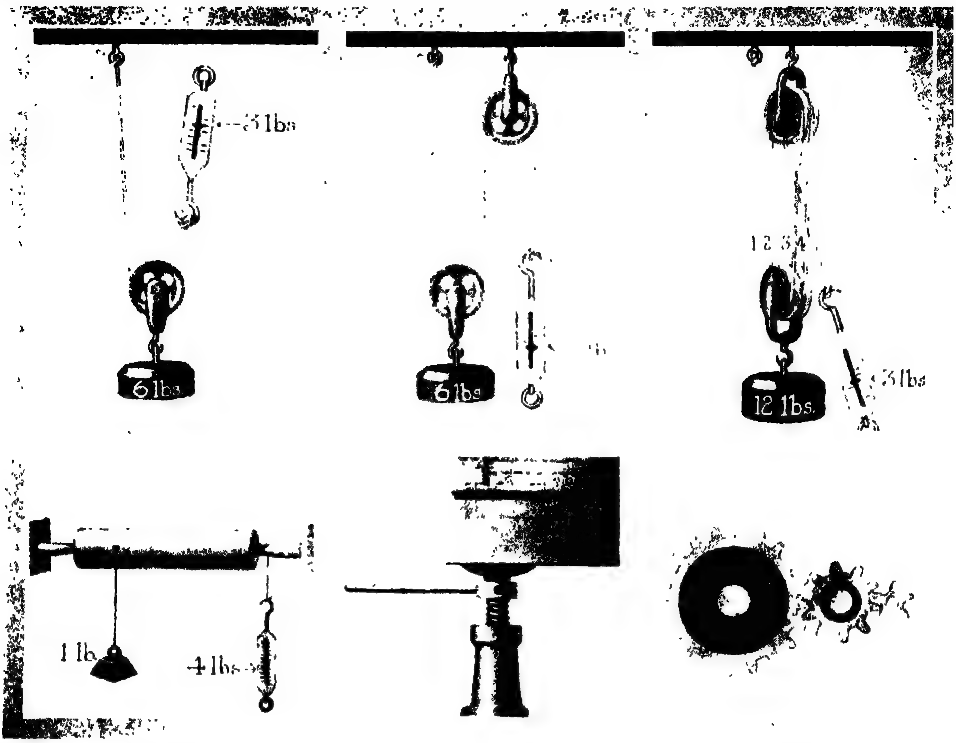
The simplest explanation is that the weight is being supported by two strands of the cord. Each strand carries half of the weight, that is, 50 pounds. In pulling, one draws on only one strand; so one needs to pull with a force of only 50 pounds.

But note also this fact: as the weight rises a distance of one foot, each strand is shortened by one foot. So one must pull out *two* feet of rope to make the weight rise *one* foot.

Now let us suppose that two pulleys are placed so that they may turn on the same axle. The 100-pound weight is attached to this double movable pulley. The necessary fixed pulleys are provided at the top to change the direction of the applied force, and a rope is wrapped continuously around, as before. The weight is now supported by *four* strands of the cord, each supporting one-quarter of the total weight. Clearly in this case it takes only a 25-pound pull to raise the 100-pound weight. And one must draw out four feet of rope for every foot that the weight rises.

The ordinary block-and-tackle pulley, used for hoisting heavy objects, contains three movable pulleys, supporting the weight by six strands. Thus, a pull with this machine is multiplied six times. It is no wonder that Henry was able to out-pull his four opponents. The broomstick arrangement was, in reality, a triple-block pulley, with six strands attached to the movable end. His puny strength was magnified no less than six times. Those who saw the contest noticed also that Henry pulled his end of the rope through a distance six times as long as the space through which the two sticks traveled. That was to be expected, since every time the sticks approached each other a distance of one inch, six strands were each shortened one inch. The six inches of loosened cord had to be pulled out by Henry.

Have you ever happened to see a lazy piano mover raise a piano by jumping out of the window? It can be done—but the indolent workman must jump, not once, but six times.



The picture in the upper left-hand corner shows a single movable pulley with which a 3-pound force can be made to lift a 6-pound weight. Upper center: single movable and single fixed pulleys. This arrangement gives no extra advantage other than a more convenient direction for pulling; you can pull downward instead of upward, as you would do with the pulley to the left. Upper right-hand corner: block and tackle consisting of two fixed and two movable pulleys. Since there are four strands on the movable pulleys, a 3-pound force can lift a 12-pound weight. Lower left-hand corner: a rolling-pin used as a wheel and axle. A 1-pound force at the rim results in a 4-pound pull at the hub. Lower center: a jack screw A small force applied at the lever can lift a house Lower right-hand corner: one complete turn of the 20-tooth gear will cause the 10-tooth gear to make two complete turns and the 5-tooth gear to make four.

When the writer saw it done, a triple-block pulley was fastened to the piano, which had to be raised three stories. The man walked up the stairs to the open window, grabbed the pulling rope, and jumped. The force of gravity pulled him down; and the piano went up. Since there were six strands supporting the piano, the man's fall of three stories raised the piano only one-sixth of the required height, that is, one-half of one story. So he repeated the operation six times; and the piano was raised!

Why a Car Cannot Be Steered by the Shaft

The wheel and axle is the third of the simple machines we shall learn the ways of. Have you ever tried steering an automobile by turning the shaft rather than the rim of the steering wheel? It cannot be done. The force your hands can exert is hardly great enough for the task. This same force applied to the rim of the steering wheel is magnified so many times that the car swerves at the slightest touch. Thus, a wheel and axle does what all simple machines do; it changes a small force into a larger one, or it changes a large force into a smaller one. The extent of this change depends upon how many times larger is the diameter of the wheel than the diameter of the axle.

Often a wheel and axle is used to produce rapid motion rather than to magnify the force applied; this is true in the case of the grindstone. One cranks the things slowly; but the emery wheel whizzes round at great speed. However, in this case the force of the crank-

ing is as many times greater than the force exerted at the rim of the wheel as the speed of the wheel is greater than the speed of the cranking.

Valuable Kinds of Wheel and Axle

There are many examples of the wheel and axle principle in everyday life. Everyone knows how a bicycle works. As you move the pedals, the sprocket wheel receives the applied force. The chains transmit this force to the axle of the rear wheel; but the size of the axle is usually considerably less than that of the sprocket wheel. So the axle turns much faster, and with it, the rear drive wheel; so the bicycle moves forward at great speed. Once you have started your bicycle and have overcome inertia, the only force holding you back is friction; and this is not very great. Should you reach an up grade in the road, however, you are at once held back by gravity. Furthermore, the pull of gravity is multiplied by the wheel and axle, so that your pedaling must overcome this much-magnified force. That is why it is especially hard to ride a bicycle uphill.

Among the many other interesting examples of the wheel and axle, the following may be mentioned: the meat grinder, the faucet handle, the door knob, and the rolling-pin. The hands of a clock, also, illustrate the same principle. Did you ever notice how much more easily the minute hand can be moved than the hour hand? The hour hand, though harder to move, revolves only a twelfth as fast as the minute hand. Here, too, the greater the speed, the smaller the force.

One of the most valuable kinds of wheel and axle is the gear. When a toothed wheel containing 100 teeth on its rim engages another wheel with 10 teeth, the 10-toothed wheel turns around ten times for every single rotation of the 100-toothed wheel. In this way rapid motion is obtained, but, as usual, at the expense of the force exerted.

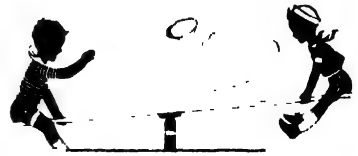
Every motorist knows that a steep hill must be "taken in low gear"; for "low gear" means slow speed and slow speed means great force. The transmission of an automobile is a collection of geared wheels that may be made to engage each other in different ways by changing the position of the transmission lever. When the engine's power is transmitted to the rear wheels by way of a many-toothed wheel that engages one of fewer teeth, high speed is the result. When this power is transmitted by way of a wheel with few teeth that engages one with a greater number, the result is low speed.

Three other simple machines have important uses in the world about us. They are the inclined plane, the screw, and the wedge.

Every staircase is a modified inclined plane. We could reach our rooms more quickly with ladders than with stairs; but we should have to exert more force in proportion to the length of time it took. An inclined plane helps us to overcome the force of gravity. That is why a roadway up a mountain side winds back and forth. The more gradual the incline, the easier it is to climb to the top but the longer it takes. Often heavy objects, such as safes, are rolled up or down an inclined plane. This simple machine works both ways. It helps us to lift a body against gravity with a force that is smaller than the body's weight, and it helps us to lower a body gradually and so avoid breaking it.

The screw and the wedge are simple machines whose action resembles that of the inclined plane. The lifting jack is an excellent example of the screw principle. By means of it, houses may be lifted off the ground. The action of the wedge is best illustrated in such appliances as the pin, the needle, spears, knives, chisels, and in the many other tools which the carpenter uses.

Will you come and take a ride upon this lever of the first class? And can you tell which child is the heavier in each pair?



Reading Unit
No. 8

WHAT IS WORK? WHAT IS ENERGY?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Why does man build machines? 1-333
What is work? 1-333
When is work done? 1-333
How is work measured? 1-338-39
What is energy? 1-339
What are different forms of energy? 1-339-41
How may a falling body release energy? 1-339-41
What is the original source of plant energy? 1-341

Things to Think About

How does an Indian bow do work?
Is work being done when a man strains to move a heavy trunk that does not budge?
How do elevators and escalators do work?
How may gravity do work?

Picture Hunt

How does the string on a bow do work? 1-340
How are the boys in this illustration doing work? 1-333
How may moving water be put to work? 1-339-41

Related Material

How may heat and light energy be produced from electricity? 1-383, 386, 522-28
How does food provide energy? 2-334, 360, 366
How is breathing related to the release of energy? 2-51
What is the source of most of our available energy? 1-341, 343-52
How may the energy of falling water be put to work? 1-370, 505, 10-398
How is work done by a steamship when it moves? 10-299-300
How do the Dutch use windmills? 6 344, 345, 352
What substances are used for fuel? 1-384

Practical Applications

How are mighty waterfalls like Niagara put to work? 1-339, 341
How is work done in road building? 1-335
How does a motorbus do work? 1-335

Leisure-time Activities

PROJECT NO. 1: Make a power house, 14-37.

PROJECT NO. 2: Make a bow and arrow, 14-39, 49.

Whenever a body moves, "work" is done. Work is done when the wind blows and when the river flows. A boy does work when he walks and when he tosses about in his sleep. He works when he eats and when he talks. Even when he plays, he does a great deal of "work," in the scientific sense of the term. Just as truly as forces tend to cause movement, so any movement on the face of the earth involves "work" that is being done.

Photos by H Armstrong Roberts

WHAT IS WORK? WHAT IS ENERGY?

We Are Here Going to Talk about These Important Words as a Modern Scientist Employs Them

ONE great difference between life and death is that living things are more likely to change. Of course dead things change, too; but they change more gradually and more slowly. When we inquire into the nature of the change that goes on among the living creatures of the world, we find that nearly always change begins with movement. Life—change—movement; movement—change—life; it is a cycle from which no one on earth can escape. Plants and animals move themselves from place to place, pushing aside objects that are in the way. Escaping from an enemy, they go from rest into motion; in catching their prey, they cause moving things to stop. In order to build a shelter, they move materials from one place to another; in order to overcome the resistance of land, air, and water, they develop ingenious ways of moving about.

Now we have already learned that only man has had intelligence enough to make movement easy. When his own muscles are too weak to overcome gravity, inertia, and friction, he invents machines to help him. With these machines he multiplies and magnifies the forces of his own body. These forces push upon objects, pull upon them, and change them from a state of rest to one of motion, or from motion to rest. Whenever a body moves, *work* is done. Work is done when a book is lifted; work is done when a stone is thrown. Work is done when the wind blows, and work is done as the river sweeps along. Man does work when he walks and when he tosses about in his sleep. He works when he eats and when he talks. Since living man is never absolutely at rest, he is performing work all the time. Just as truly as forces tend to cause movement, so any movement on the face of the earth involves *work* that is being done.

In the several paragraphs below are samples of work being done. Read them carefully, for each contains an important idea

which scientists hold about the work of the world.

* * * * * * * *

A hunting expedition slowly forced its way through the jungle. The guide headed the procession, followed by the two men who were paying the expenses of the trip. After them came a long line of natives, each carrying a heavy pack. With bodies bent double by the load, the carriers stumbled on, over tangled vines and through thorny bushes. Several times an hour they were forced to stop, to catch their breath and to rest their aching muscles. Perspiration dripped from every pore of their bodies. All this work, in order that a few men might live in the jungle for a week in reasonable comfort!

* * * * * * * *

"Your Highness," said Archimedes to the King of Syracuse, in ancient Greece, "I am not a very strong man, but I can move any weight whatever. If there were some firm object not on the earth against which I could lean, I might even move the earth wherever you wished."

The King was amused; but he knew from experience that Archimedes' ideas were to be respected. "Prove it," he said. "Do you see that large galley anchored offshore? Let me see you pull it in on the sand."

Archimedes got ropes and levers and pulleys, and arranged them so that his own weak effort was magnified many times. Unaided by any other human force, he made good his boast. The galley was soon resting on the sand.

* * * * * * * *

A boy went into a hardware store to buy a brass curtain rod exactly thirty-one inches long. The clerk measured off the desired length on a solid metal rod that was very much longer. "How are you going to cut it?" asked the boy. "Wait and see," was the reply. The clerk placed the rod between the jaws of a long shearlike tool, set exactly at the mark on the rod. "Here," said he to the boy, "cut it yourself." The boy then pulled the lever and the jaws bit through the half inch of metal as if the rod were butter.

* * * * * * * *

Photo by Field Museum

Stumbling over tangled vines and through thorny bushes, the native carried the tired huntsman for miles. In order to calculate the "work" accomplished, we should need to know, not only the distance covered, but the amount of resistance offered by the road to the combined weight of the men.

In another chapter we have already told you how a man once raised a piano by jumping out of a window.

Ridiculous, do you say? Well, it is often done by piano movers who would rather permit gravity to do work upon their bodies than to work with their bodies to overcome gravity. Let us explain.

The piano is attached to the movable end of a triple-block pulley. Six strands support its weight. The piano mover walks up the stairs and to the third-floor window into which the piano must be lifted. He looks down at the piano on the street below. In front of him is the pulling rope, dangling from the pulley fixed to the roof cornice. He grabs the pulling rope and jumps. But he does not fall very fast. When he reaches the street, the piano has gone up half a story. Asking his helper to hold the rope, he mounts the stairs again and repeats his leap. The piano is now one-third of the way up. Four more jumps and the piano is at the third-floor window!

* * * * * * * *

In the factory where water is artificially frozen into large cakes of ice, a long and gradually inclining chute reaches from a floor above to the waiting trucks below. A man stands at the head of the chute, where a crane lowers cake after cake to the slide. The cakes are so heavy and the incline so gradual that the ice does not move. So the man gives each cake a shove as it is lowered. Down it goes, into the empty truck below.

* * * * * * * *

WHAT IS WORK? WHAT IS ENERGY?

After the fire was put out, the site where the building had stood held a huge heap of charred beams, shattered brick, and broken glass. It was most unsightly. A wrecking crew of two men appeared, one on a dump truck and the other on a lumbering steam shovel. They began work at eight o'clock. A fire was built under the boiler and steam was soon hissing from the valves. The mighty jaws of the shovel swung over the pile of rubbish, fell down upon it, bit deeply, and closed. At a throw of the lever the shovel rose, swung toward the truck, and deposited its huge mouthful. Tirelessly and ceaselessly it continued these movements until the truck was filled. Another truck rolled up, received its load and drove away. By noon the entire lot was clear and clean. Not a piece of junk remained.

All this tremendous work a modern machine can accomplish. It would take hundreds of men to equal the achievement in the same length of time.

* * * * * * *

How should you like to live in a house on wheels? All the conveniences of a modern dwelling are to be had in this bungalow built upon an automobile chassis that can travel to any spot to which the owner wants to go. The gasoline engine that moves the car also pumps the running water through the plumbing of the house. The same engine generates the electric current with which the house is lighted, provides electricity for the stoves, rings the doorbell, drives the washing machine, and operates the radio. On warm days the engine furnishes energy with which to cool the air, and on cold days it sends current with which to heat the fireplace. Day and night, throughout the year, it keeps the refrigerator well provided with ice. This marvelous engine, in return for all the work and service it does, asks for very little: a certain amount of care and attention and plenty of water, oil, and gasoline.

* * * * * * *

When the elevator was full, the attendant pushed a button and the two gates shut automatically. Two tons of matter then began its rapid climb, defying the pull of gravity. Someone wished to get off at the 89th floor; whereupon the operator pushed button No. 89. When the floor was reached, the car leveled itself exactly and both gates sprang open. The entire trip to the 102nd floor--more than 1,200 feet above the street--took four minutes.

* * * * *

Tons of water dropped vertically through a large pipe and down upon a wheel. The wheel spun round at a terrific speed, turning with it a huge dynamo. There was, in fact, enough water for a dozen such electric generators, all of which pumped their energy into a network of wires that spread out over an area of hundreds of square miles. There the electricity was tapped from the wires to light homes, drive trolley cars, toast bread, play radios, operate machines, and do work of all sorts. Some of the energy was even used to light lamps in a hothouse where electricity helped plants to grow. The entire power system was under the careful observation of a handful of men. Most of the time these men had little to do. They watched instruments, made notations, pushed buttons, threw switches, and telephoned to each other at regular intervals.

* * * * * * *

"Watch out for that trunk!" came the warning cry when a pedestrian seemed about to be hit by a piece of luggage tottering above his head on the edge of a trunk. He reached up to ward off the blow and found himself being pushed down by a great weight. He was just strong enough to keep the trunk from crushing him to the ground. The trunk did not budge; and neither did he. It was a clumsy situation. Straining every muscle

and with perspiration running down his face, the man kept his position. It was five minutes before the men could bring him relief. "Whew! That was hard work!" said the pedestrian. "Why, he did no work at all," said a professor of science who had witnessed the accident.

* * * * * * *

John came home to supper after playing a game of football. Jim came home after spending the day studying in the library. "Gosh, I'm tired," said John. "So am I," countered Jim. "Oh, how can *you* be tired?" replied John, "you did no work at all. Just sitting in a chair with a book! I *worked!*"

Without taking sides in the argument as to which of the boys spent his time most profitably, can you see any truth in the idea that John had *worked* the harder and that Jim had done no *work* at all?

* * * * * * *

On the cold gray morning of December 2, 1942, a small group of scientists gathered in the handball court underneath the West Stands of Stagg Field on the campus of the University of Chicago. Before them, as they stood and talked with hushed voices, was a huge, dark, knob-shaped structure, one unlike any other ever built by man. Scientists spoke of this secretly built device as the "pile," for it was really a pile of carbon and uranium (ū-rā'nĭ-ŭm) blocks.

One of the learned men slowly takes his watch from his pocket. "Very well, gentlemen, let's go," he murmurs. The group shuffles into a small shack at one end of the court. Inside the brilliantly lit room is a huge control board, a maze of colored lights, dials, and electrical instruments. A hush falls over the group as one of their number turns several small dials. "All cadmium strips have been removed except one," he reports.

All eyes are focused on the meter above which is a neatly lettered plate bearing the words "Temperature of Pile." As the operator's hand turns the lever, the needle of the meter upon which all eyes are fixed begins to crawl upward. 90° . . . 95° . . . 100° . . . 110° Fahrenheit. Hold it!

A murmur sweeps over the group.

"It's working!"

"Our predictions have come true!"

"The pile works!"

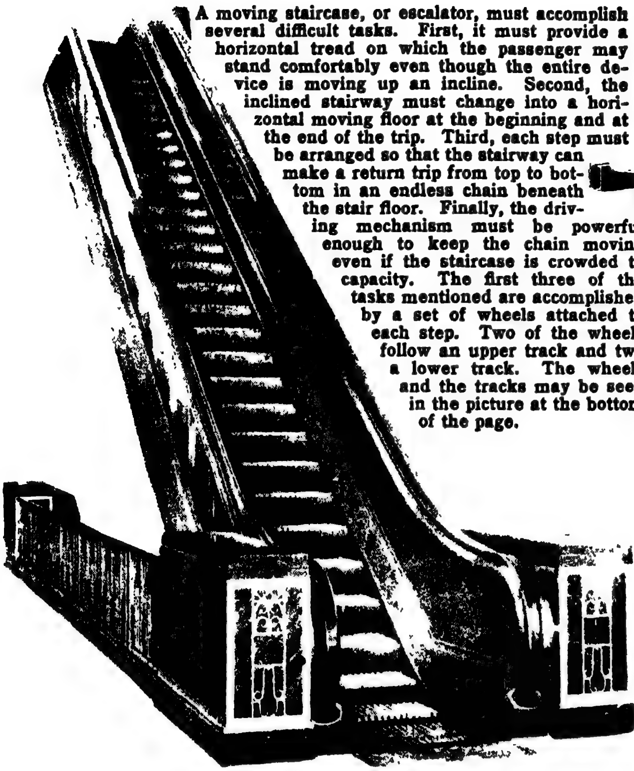
The operator, however, does not let his eyes leave the meters, for he knows that he is keeping a Titan from running wild, a Titan who, if left without control for even a few seconds, would break his bonds and work havoc. That last cadmium strip must not be withdrawn too far, for if it is, the heat generated in the dark mass of material under the stands would be so enormous that it would result in a genuine catastrophe.

In each of the several paragraphs above, some form of work is being accomplished. Yet, upon close examination, many differences appear. In the case of the men in the jungle, the work is done in the most primitive way—the only way man knew until very recently. The natives exerted muscular force against the resistance of gravity and friction. The amount of work they performed depended upon two things: the size of the force necessary to keep moving and the distance covered. A good method of paying the men for their work would have been to consider the weight of their packs, the roughness of the road, and its length.

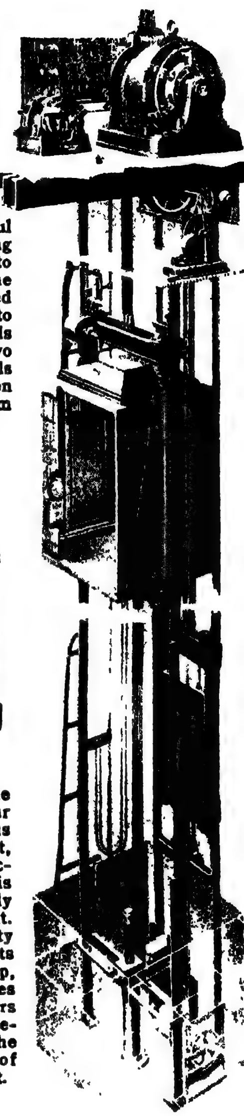
When we come to the story of Archimedes, we note that an incredible amount of work may be done by one human being if the latter makes use of machines operated by his muscles. Having learned the ways of pulleys, we may be sure that Archimedes pulled weakly over a long distance in order to make the heavy galley move over a short one. Nevertheless, the amount of work done may again be measured by two things: the size of the force exerted and the distance covered by Archimedes; or, the size of the resistance overcome and the distance through which it moved.

The boy in the hardware store makes use of another simple machine, or rather, two of them: the wedge and the lever. Here, too, the work done is the result of a large cutting force moving through one-half inch of metal.

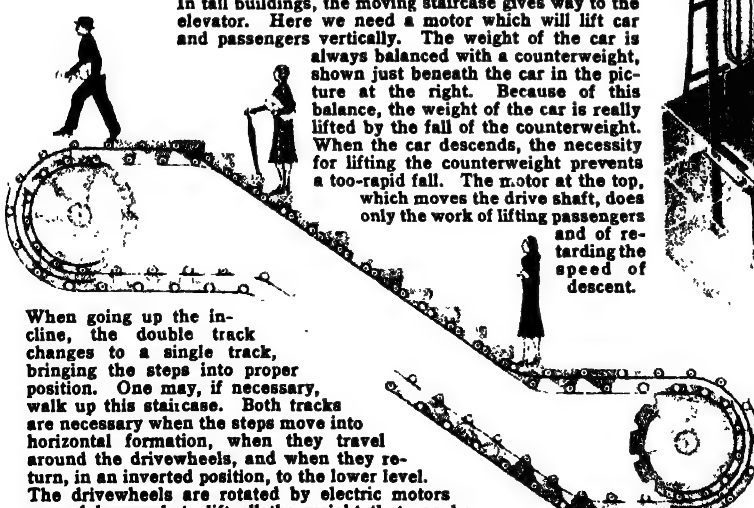
The lazy piano mover working against gravity permits his own small weight to fall six times through the desired height in order to move the heavy piano only once through that height. The work done is the product



A moving staircase, or escalator, must accomplish several difficult tasks. First, it must provide a horizontal tread on which the passenger may stand comfortably even though the entire device is moving up an incline. Second, the inclined stairway must change into a horizontal moving floor at the beginning and at the end of the trip. Third, each step must be arranged so that the stairway can make a return trip from top to bottom in an endless chain beneath the stair floor. Finally, the driving mechanism must be powerful enough to keep the chain moving even if the staircase is crowded to capacity. The first three of the tasks mentioned are accomplished by a set of wheels attached to each step. Two of the wheels follow an upper track and two a lower track. The wheels and the tracks may be seen in the picture at the bottom of the page.



In tall buildings, the moving staircase gives way to the elevator. Here we need a motor which will lift car and passengers vertically. The weight of the car is always balanced with a counterweight, shown just beneath the car in the picture at the right. Because of this balance, the weight of the car is really lifted by the fall of the counterweight. When the car descends, the necessity for lifting the counterweight prevents a too-rapid fall. The motor at the top, which moves the drive shaft, does only the work of lifting passengers and of retarding the speed of descent.



When going up the incline, the double track changes to a single track, bringing the steps into proper position. One may, if necessary, walk up this staircase. Both tracks are necessary when the steps move into horizontal formation, when they travel around the drivewheels, and when they return, in an inverted position, to the lower level. The drivewheels are rotated by electric motors powerful enough to lift all the weight that can be crowded upon the stairs.

Photos by Otis Elevator Co.

of a force moving through a distance. Note that the distance is measured in the same direction in which the force is acting. Gravity exerts the pull.

The ice cakes sliding down the chute furnish a somewhat more complicated instance of work being done. The weight of the ice which is the force of gravity acting upon it - pulls downward vertically, as always. Yet the motion of the ice is on an incline. Here we must distinguish between the amount of work which the man does and the amount of work which the force of gravity itself performs on the ice. The man shoves the cake, in that way overcoming inertia and friction. That is all the work he does. Gravity does the rest. In calculating the amount of work performed by gravity, we multiply the weight of the ice cake by the vertical drop. It does not matter how long the incline is.

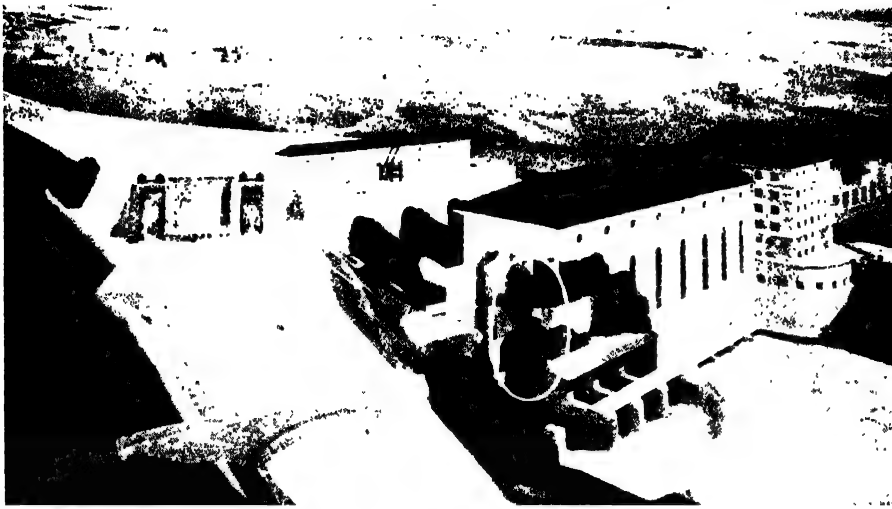
The four instances which follow the incident of the ice cakes represent the progress which man has made in his ability to perform work. Not only has he applied machines which magnify tremendously his meager bodily force, but he has learned to dispense with this force altogether. Instead, he calls upon the steam engine, the gasoline engine, the electric motor, and the water turbine. He himself pushes buttons or throws levers. Nevertheless, the amount of work accomplished is determined by the same two factors: the force exerted by the engine and the distance through which it moves—always measuring the distance in the same direction as that in which the force acts.

Shouldn't you hate to be under this rock if it should fall? Standing as it does, balanced, seemingly, on a mere point, it possesses potential energy. Were it to fall, its energy would change to the kinetic energy of motion. Upon its striking, this energy would change to heat.

The two instances which follow the four above referred to are somewhat puzzling. Does the pedestrian pushing the motionless trunk do any work? And does Jim, the student, do work when he sits quietly studying? According to the scientist's definition of *work*, they do not. In neither case is there any motion. True, the force exerted in the pedestrian's case is great enough; but it results in no movement. So the *work* accomplished is zero. As for Jim, he may feel very tired, but he has done no work, in the scientific sense of the word.

To repeat, the scientist calculates work by multiplying a *force* times a distance Since forces are measured in *pounds* and distances in *feet*, work is measured in *foot pounds*. When a man lifts a ten-pound weight through a height of five feet, he performs 10 times 5, or 50, foot pounds of work. Again, when this same weight is dragged horizontally for five feet against a retarding force of friction equivalent to two pounds, the amount of work done is 5 times 2, or 10 foot pounds. It usually takes less *work* to drag a weight than to lift it.

Finally, we come to the experiment performed in the handball court on the campus of the University of Chicago. Here we see one of the early attempts to convert matter directly into energy. The experiment was a forerunner to the development of the atomic bomb, which helped to bring to a successful



All moving objects possess energy, for they are able to do "work." Here we see a large body of water that is stored at an elevation and permitted to flow down to the water turbines in the power house. As it stands in the reservoir, the water has potential energy. This is changed into kinetic energy as the water flows. As the water is made to turn dynamos, the kinetic energy is changed into electric energy.

close the terrible Second World War.

What Is Energy?

The ability to do work is called energy. "Energy" is another of the terms which, like "acceleration," "force," and "work," has taken on an important and special meaning in science. Let us try to understand this meaning.

Anyone who suddenly finds himself under a heavy safe that is dangling in the air, is quick to get "away from under." If required to explain this feeling of uneasiness, one might point to the consequences, should the safe fall. The scientists' explanation would be that the safe in the air possesses an ability to do work, that is, it possesses "energy." Should it fall, it would give up that energy at the point where it came to a stop. If the safe weighs 2,000 pounds and falls through a distance of 50 feet, the amount of energy released at the end of the fall would be 2,000 times 50, or 100,000 foot pounds. Think of being suddenly overwhelmed by so much energy!

How Falling Bodies Release Energy

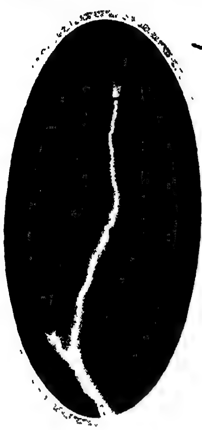
That falling bodies release energy in this way is well known. Falling water is an excellent illustration, for we use the energy released by the fall to drive water wheels. The wheels turn dynamos that generate electricity for doing the world's work.

All moving objects, in fact, possess energy, for they are able to do work. The winds moving air -do work in blowing objects about and in raising waves in the ocean that grind rocks into sand. Flowing rivers do work when they wear away the soil. They cut deep valleys across continents, and carry each year millions of tons of matter to the oceans. If someone were to stop the earth in its motion, countless trillions of foot pounds would be released. It is fortunate that there is nothing in space to stop the movement of the heavenly bodies, for they possess tremendous amounts of energy, by virtue of their motion. This energy is never released in any appreciable amount.

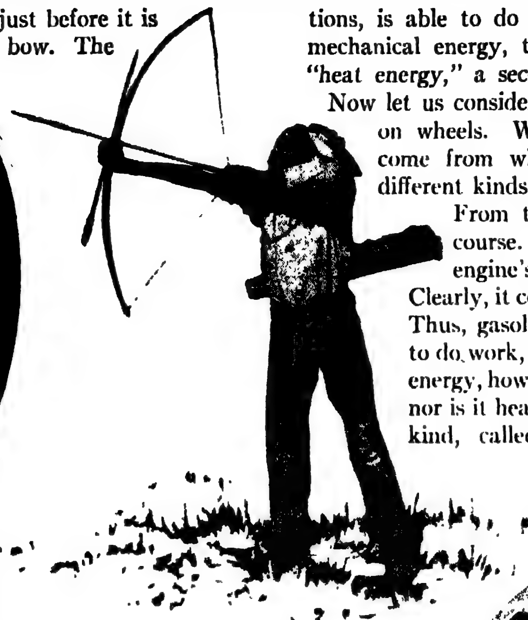
Why a Bow Can Do Work

Bodies not only possess energy by virtue of their position as in the case of the dangling safe or by virtue of their motion as in the case of flowing water- but also by virtue of their condition. Let us take the

case of an arrow just before it is released from the bow. The



For thousands of years men have watched lightning flash across the sky and have observed its dire effects, but only lately have they found out that it is a form of energy, which they are able to duplicate on a small scale in the laboratory.



Bodies not only possess energy by virtue of their position, or by virtue of their motion, but also by virtue of their condition. This gives energy to the tightly stretched thong of the bow, just before the arrow is released.

arrow is perfectly still; the bowstring and stick are stretched to the limit. The bow possesses energy by virtue of its stretched condition; for, when the hold is released, the arrow flies out and is able to do work. The same is true of a stretched rubber band or a wound-up clock spring or phonograph motor. They possess energy even when motionless, for they are able to do work when released.

There are several different kinds of energy. Energy by virtue of position or of motion or of condition, in the sense described above, is called "mechanical energy." But mechanical energy is not the only kind of ability to do work in the world about us. Consider the following:

The blazing fire in the furnace of the steam shovel is undoubtedly responsible for the work which the shovel does. The heat of the fire boils the water, the water changes to steam, and the pressure of the steam operates the engine. So the jaws of the shovel dig into the ground because there is heat in the fire. Evidently heat, under certain conditions, is able to do work. In addition to mechanical energy, therefore, there is also "heat energy," a second kind of energy.

Now let us consider once more our house on wheels. Where does the energy come from which performs all the different kinds of work in the house? From the gasoline engine, of course. But where does the engine's energy come from? Clearly, it comes from the gasoline. Thus, gasoline, having the ability to do work, possesses energy. This energy, however, is not mechanical, nor is it heat energy. It is a third kind, called "chemical energy."

We know that the gasoline combines chemically with the oxygen in the air, and that in doing so, it produces great quantities of gases that seek a way out of the engine's cylinders. The pressure of these gases moves the engine in this way, making it possible for the engine to do work. It is the chemical energy in dynamite which moves mountains.

Heat is a form of energy and under certain conditions it is able to do work. It required energy to make this steel beam glow. Some of this energy is now being radiated away from the beam.

For a fourth kind of energy let us turn to the elevator that lifts passengers to the 102nd floor of a tall building. Where does the energy for doing this work come from? The electric motors which wind the cables that lift and lower the car, can do nothing by themselves. They must be supplied with electricity. So must the locomotives in an electrified railroad and the motors which

drive a heavily laden subway train. Electricity, therefore, is also able to do work. The fourth kind of energy is called "electrical energy."

Where Plants Get Their Energy

The fifth form of energy is one that is most important to us as living creatures. It is certainly the most difficult one to understand.

Has it ever occurred to you that our lives depend almost entirely upon plants? The growth of plants purifies the air we breath, and from their bodies we get food and shelter and clothing. Even the meats we eat come from animals that feed, chiefly, on plants. Fish, too, thrive mostly on plants, or on smaller fish that feed on plants. The food we eat is, of course, chemical energy that gives us our ability to walk, to run, to speak, and to do our work.

But where do plants get *their* energy? Place a growing plant in the dark and you soon find out It is light—sunshine—which, more than anything else, is responsible for the growth of a plant. The sun sends us a kind of energy which is different from the others we have mentioned. It is certainly energy, because work can be done by means of it; but it is not mechanical energy. Neither is it chemical energy or electrical energy of the kind we have been describing. A good deal of the energy of the sun comes to us as heat energy; but the rest of it is in the form of light.

It can be said, therefore, that plants are storehouses of sunshine; and that the energy which they furnish to all animals, including man, is derived from the light energy of the sun. The light energy sent to us by the sun many millions of years ago is to-day stored in coal and in oil; for we believe that coal is the remains of ancient plants buried deep in the ground and that oil is the remains of certain forms of ancient plants and animals. The sun is like a gigantic broadcasting station which sends vast amounts of light energy into space. We on earth catch only a little of this energy; but out of it we build our bodies, our homes, and our very lives.

For a sixth form of energy, let us consider again the experiment performed on December 2, 1942, on the campus of the University of Chicago. For the first time in the history of man there was built a self-sustaining "pile" for the release of "nuclear (nū′klē-ăr) energy." It was the first man-made atomic (ă-tŏm′ĭk) power plant on earth. A sufficient amount of fissionable uranium—that is, of uranium in which the atoms could be split up—was brought together to start a chain reaction, or one in which the first reaction start. another and the reaction will in this way keep on indefinitely. Within the "pile" the uranium was being converted to other elements, some similar to those found in nature and several others never found naturally. Most important was the fact that, in addition, heat energy was being produced.

Apparently, as the uranium changed to other elements some of its mass disappeared completely. Thus, matter was being destroyed. It was being changed into heat energy. In other words, we can now consider matter itself as a form of energy. Since the energy comes as a result of a rearrangement of the heart, or nucleus, of uranium atoms, scientists call this sixth type of energy, "nuclear energy."

At the present time we are only at the beginning of our study of nuclear energy. We do not yet know how to generate it efficiently or how to control it for the welfare of mankind.

PHYSICS

Reading Unit No. 9

HOW ENERGY GOES ON FOREVER

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the origin of coal? 1–343-44

How large were prehistoric ferns? 1-344

Where may light energy be stored? 1-346-47

Harnessing the energy of steam, 1-347

What may plants use as a substitute for the sun? 1–347-48

Where does energy go after man uses it? 1-349-51

Will the energy of the universe ever be used up? 1-351-52

Things to Think About

How is it possible for an electric bulb to supply us with energy which came originally from the sun?

How do plants make use of the sun's energy?

What are all the possible changes of energy from one form to another?

Picture Hunt

How may energy be obtained from the sea? 1-345

How can energy be obtained directly from the sun? 1-348

Related Material

How do bacteria help produce coal? 2–16, 20

Is it possible to exhaust our supply of coal? 1–352

What fossil markings are found in coal? 3–6, 29

What are the different varieties of coal? 9-438, 440, 445

What are the chief sources of the world's supply of petroleum? 9–449, 452, 455

What are the chief sources of energy for electric current? 1–113, 503-11, 515

Practical Applications

How is the energy of sun, coal, water, and steam transformed into more useful forms of energy? 1–339, 344-50

How is energy sent over great distances to farms and small towns? 1-345

Leisure-time Activities

PROJECT NO. 1: Make a collection of different kinds of coal.

PROJECT NO. 2: Make a collection in bottles of safe liquid fuels.

Summary Statement

Energy can neither be created nor destroyed, but when energy changes its form, some of it turns into heat energy that cannot be used for the activities of life.

Millions of years ago there grew in certain swamps and marshes a dense forest of huge fernlike plants. In the course of ages these strange forests were buried. This story tells how their decayed matter turned eventually into coal. You may read about the Carboniferous Age, the age when these great forests flourished, on other pages of these books, where we tell of the record of the rocks and the story of geology.

HOW ENERGY GOES ON FOREVER

Not a Bit of It Can Ever Be Created, and Not a Bit Can Be Destroyed

WE WISH to tell a story that began very long ago, but if we should start by saying, "Once upon a time" our readers may think back over a period of perhaps a hundred years. That would not be enough. Even five hundred years would not be enough. Our story begins long before Washington crossed the Delaware, many years before Columbus discovered America, and even longer ago than the time of King Arthur and his Round Table. In fact, we should like our readers to carry their minds back to the days before Christ, before the Romans, before the Greeks, and before the Egyptians. Having succeeded thus in going back six thousand years or more, our readers may now be able to see still further into the dim past, until they glimpse a time when there were no men upon the earth. Indeed, our story begins, not thousands, but millions of years ago.

One can only guess what the earth was like then; but there is reason to believe that one could find continents and oceans, soil and air, rain and sunshine. Under such conditions plants would grow. Our story begins with a ray of sunlight which fell upon the leaf of a gigantic fernlike plant that grew in a hot, swampy, steaming jungle.

The fern grew big and strong. It fed upon the water and the air and drew up from the soil other materials which it needed; but especially did it absorb the warm sunshine Without the energy of the sun, it could not live. Here and there were several of its companions, most unfortunately thrown into

the shade, where they grew sickly, faded, and withered because they could not get enough light. Of water, of soil, and of air there was plenty; but not all could find a place in the sun.

Our fortunate fern prospered and in time gave birth to many others of its kind. They, too, were lucky enough to catch the energy of the sun in their leaves. Soon there was an immense jungle of huge ferns, each stretching its branches in such a way as to trap the sunlight which continued to pour down day after day and year after year. Imagine a fern with stem five feet thick and branches fifty feet in length! Such growth could not continue long without interference among plants so close together. Soon some of the many ferns were shut off from food and from light. They died and decayed; but from their dead bodies other ferns grew. In time the swamp contained layer after layer of packed and decaying leaves, stems, and roots. Above it all was the jungle of living ferns reaching up to the sun.

Photo by International News Photos

A powerful steam geyser was recently released by drillers near Rome, in Italy. At a depth of 900 feet they struck steam under such pressure that its temperature was about 350 degrees Fahrenheit. The steam is being used to drive dynamos which generate electrical energy.

How the "Black Rock" Was Formed

And then this scene of plenty was disturbed by a great calamity that befell the region. Because of changes in the crust of the earth, the swamp had been settling slowly for some time. Finally the ocean flowed in to cover the jungle with sand and silt. The weight of the water compressed the decaying ferns so that they hardened. Many years later, due to new movements in the earth's crust, the water was drawn off. New ferns sprang up in the swamps that remained. Let us, however, continue to follow the history of the fern forest now decaying and hardening under tons of sand and silt.

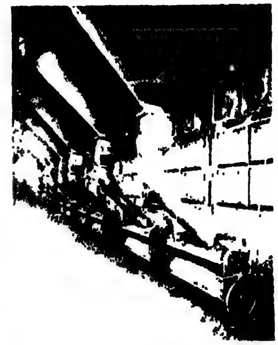
Thousands of years passed by. Each year found the decaying material more compressed and more hardened; but in it there still remained the energy of the sunshine which the fern leaves had long ago received from the sun. Nothing of any importance happened to our forest underground until man came upon the scene. By that time the earth's crust had gone through many new changes. Due to tremendous pressures upon the ocean bottoms, many of the continents had been pushed upward near the shores. Mountain building had been followed by a twisting and crumpling action in many sections of the earth. The layer of decaying ferns which had once been a jungle was also twisted, so that one small part of it was pushed upward and exposed to the air. When savage man saw the outcropping, he was puzzled by its strange appearance. Not finding it especially useful, he called it "black rock," and dismissed the matter from his mind.

One winter a hunter sat shivering on a ledge of this "black rock." He was starving from hunger and numb from cold. The wind howled and blew the icy snow all about him. Far from his village or from anyone who could help him, he slowly froze to death. If only he had known that right beneath him, in that ledge of "black rock," was warmth in plenty! If only someone had whispered to this poor hunter the secret that the "black

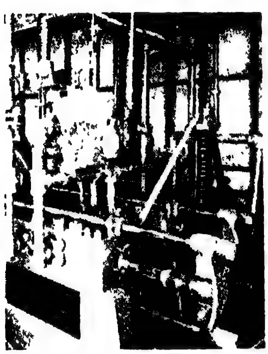
HOW ENERGY GOES ON FOREVER

Millions of years ago the sun's energy was caught by plants in this ancient forest, and stored by them in the form of sugars and starches.

After many changes had come about, these plants were formed into coal beds, from which we remove blocks of energy in the form of coal.

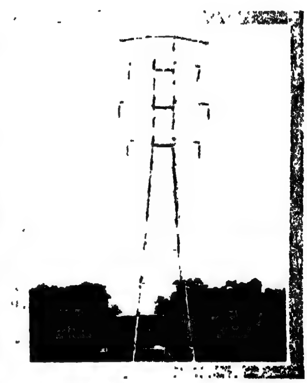


Here we see the coal stoked into furnaces, where the energy which was once the sun's is released in the form of heat when the coal is set on fire.



The heat from the coal boils water into steam, which is crowded into tanks under great pressure. When t escapes, it can drive engines.

The mechanical energy of the engines can be used to drive dynamos. Thus the dynamos are being moved by energy which was once the sun's.



The dynamos generate electrical energy which is sent out into tall transmission cables that run for miles through the countryside.

Finally the electric current reaches a modern home, where the electrical energy operates electric stoves, lamps, and other devices.

Some of the electric current is carried to a greenhouse, where it lights lamps that stimulate the growth of plants.

The same sun is still shining to-day, and we need not depend upon ancient sunshine in the form of coal in order to grow our food.

rock" was coal; that it could be set afire and be made to release the energy which it contained. It seems strange to us, who have learned how to make fire and to feed it with coal, that anyone should freeze to death while sitting on a mass of coal. Yet that is what surely must have happened in the past. or whether they are the remains of very ancient plants, as is our useful coal. Let us see how this is accomplished in one very important instance.

On the East River, which bathes the shore of Manhattan Island, the heart of New York City, a daily procession of barges delivers

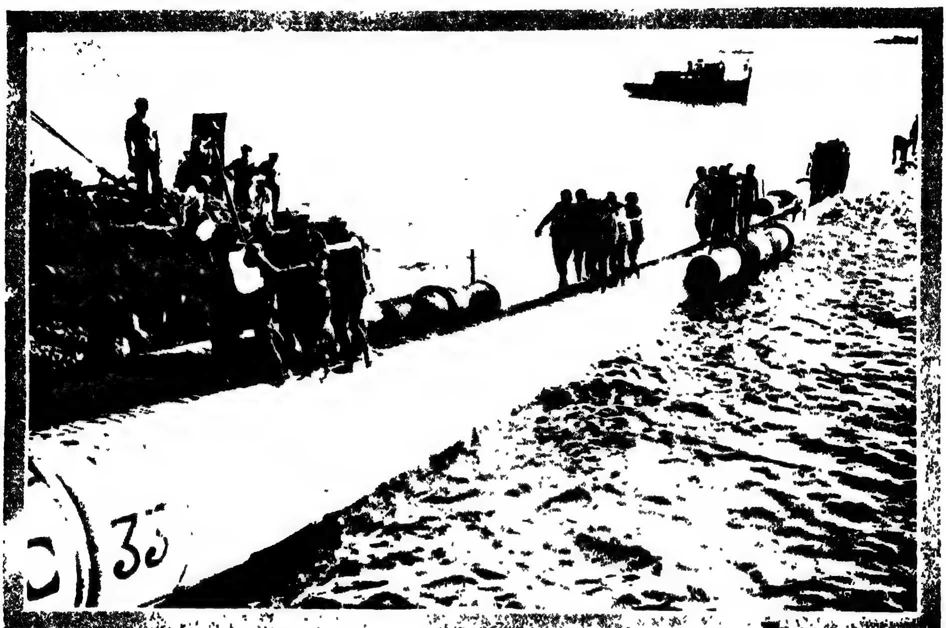


Photo by International News Photos

The search for new sources of energy has led Professor Claude, the inventor of the neon lamp, to the cold waters beneath the surface of the sea. At Matanzas Bay, Cuba, the surface waters are warm; but lower down the water is cold. This difference in temperature can be used to operate a steam power plant, provided the cold waters can be pumped up. After two unsuccessful attempts and an expenditure of a million dollars, Claude succeeded in sinking this mile-long steel pipe through which the cold water was tc be raised. If this scheme can be made to work successfully it will, in time, be immensely valuable.

Only quite recently has man learned to dig in mines for the warmth of sunshine caught and trapped millions of years ago by a forest of ferns that has turned into coal.

Borrowing Light Energy

Every leaf knows the secret of trapping the light energy which the sun sends out. Although man has not yet been able to discover this secret, he does not hesitate to take from the plant world the stores of energy they have laid up. This, man does by eating plants of many descriptions and by using them in various other ways. It does not matter whether the plants are recently grown coal by the thousands of tons to a so-called power plant. The coal is fed into a long line of furnaces where raging fires are kept burning. There the energy of ancient sunshine is changed into heat energy. But the heat energy is not permitted to escape. It is at once transmitted to metal boilers containing water. The water is changed into steam. Thus the energy of the sun which once fell upon the leaves of a fern, now heats the water, tearing its molecules apart so that the liquid becomes a gas.

But gaseous water occupies about seventeen hundred times as much space as does liquid water. The boilers, though large, are

The sun is so hot that if the earth were thrust into it we should last no longer than a snowflake on a red-hot stove. But the sun is 93,000,000 miles away from us, and so its heat is endurable. Actually, the earth receives less than one two-hundred-millionth of the energy sent out by the sun. Yet this tiny fraction means the difference between life and death to us. Every square yard of the earth's surface receives from the sun more than enough energy to raise the temperature of a pound of water one degree F.

hardly large enough to provide place for all the steam without requiring that the steam be greatly compressed. This pressure is tremendous. There is one instance in which a boiler was not strong enough to hold so much steam. The steel drum exploded, sending fragments of steel plate through several feet of brick wall and across a street fifty feet wide. Thus the heat energy at the moment of explosion was changed into energy of motion; that is, into mechanical energy.

What Happens to the Sun's Energy

But boilers do not often explode. At the proper time, and when man so decides, the steam is permitted to rush out into an engine called a steam turbine. The turbine wheel receives all the stored-up mechanical energy and spins round at terrific speed. As we watch the huge wheel whirl and hear its musical hum, we must bear in mind the fact that many millions of years ago the energy of the turbine was the energy of the sun.

The spinning turbine is, after all, not the thing which man is after. So he couples the wheel with the rotating part of an electric dynamo. Now it is the dynamo which whirls, generating electric energy at every turn. This energy is forced into a vast network of wires that stretch under the streets and buildings of a city that houses millions of human beings. On some fine morning, in a house perhaps ten miles from the power plant, a boy calmly inserts a slice of bread in an electric toaster. A minute later a click in the toaster gives notice that the bread is ready to be eaten. As the boy brings the warm brown toast to his mouth, he is probably quite unaware of the fact that the energy which made his food more palatable is the same which fell on the leaf of a plant millions of years ago.

Not all of the electric energy from the dynamo goes to heat electric toasters. Much of it flows into electric lamps, where the wire filaments get so hot that they glow. In this way the ancient light of the sun becomes light again. Energy, after numerous changes in form, has resumed its original form.

An Assistant to the Sun

On the outskirts of the city there is a building where special vegetables are grown under just the right conditions. One of these conditions is the proper amount of a certain kind of light. Even the sun cannot be depended upon to provide this light when needed and in the desired quantity. So a special type of electric lamp is used as an assistant to the sun. The vegetables thrive under this light as they do under the sun. They often grow more quickly and reach a larger size. Their color is more attractive,

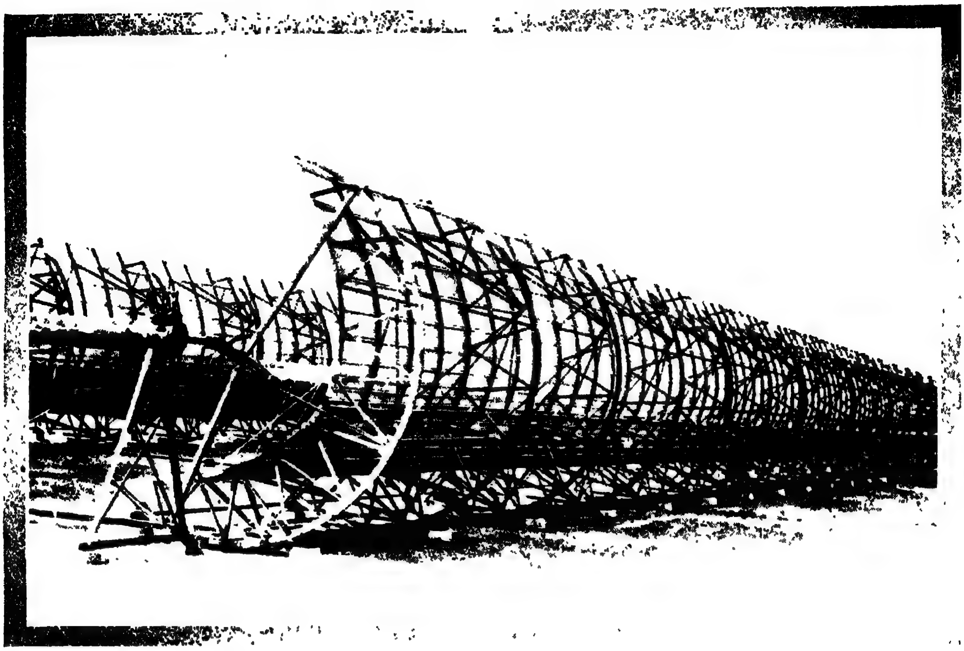


Photo by Keystone View Co.

Some day—though not for several generations, of course—our supply of coal and oil will give out. Then we shall probably make direct use of the energy which the sun is constantly pouring down on us. The sun-power plant above catches the sunshine on curved mirrors and focuses it upon boilers filled with water. The idea is to generate steam, but the power plant at present is only 3 per cent efficient.

their shape more symmetrical, and their flavor is often finer. A tomato grown in this way has in it some of the energy sent out by the electric lamp. Since this energy is the same which once fell from the sun upon a fern of long ago, the original energy is once again to be found within a plant.

Using Energy a Million Years Old

The story of what happens to the energy sent out by the sun is, in a sense, a never ending one, for it is always possible that yet another change may be wrought in the form which energy may have taken at any given time. In the case of the tomato described in the previous paragraph, a new series of energy changes begins just as soon as it is eaten. When it enters the human stomach, a chemical action takes place. The chemical energy in the tomato, a good deal of which was once the electrical energy in the lamp, is absorbed by the human body. There it provides the heat energy which maintains the bodily temperature and the mechanical energy with which one may walk, run, jump, talk, and eat. So it may be said that the person eating the tomato grown in the manner described is able to walk with the same energy which millions of years ago was absorbed by a plant. Throughout the ages this energy has existed, in one form or another. After residing in the human body for a while, it may be converted into some other form of energy and go elsewhere; but we may be sure of one thing: the energy never disappears.

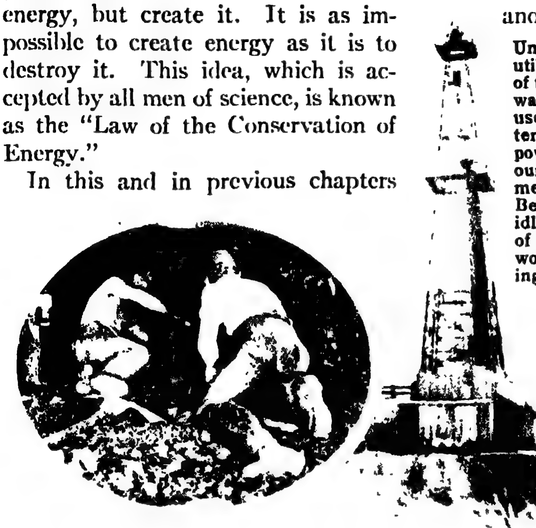
The Law of the Conservation of Energy

If one should ask, "What *does* happen to the energy in the tomato after it is eaten and after it has been used in walking?" the reply would be that it changes into heat energy. As one walks, the bodily movements heat the body, the pavement, and the air about both.

The most important reason why scientists believe that perpetual motion machines are impossible is that from such a machine energy

could be continually derived without any energy ever being supplied. Thus, a perpetual motion machine would not transform energy, but create it. It is as impossible to create energy as it is to destroy it. This idea, which is accepted by all men of science, is known as the "Law of the Conservation of Energy."

In this and in previous chapters we have been talking about five different forms of energy. Let us make a list of them and give each a symbol.



Form of Energy	*Symbol*
1. Mechanical	M
2. Heat	H
3. Electrical	E
4. Chemical	C
5. Light	L

Now let us make a list of all the possible changes which may occur, using the symbols to save space.

1. From M to H	11. From H to L
2. From M to E	12. From E to H
3. From M to C	13. From C to H
4. From M to L	14. From L to H
5. From H to M	15. From E to C
6. From E to M	16. From E to L
7. From C to M	17. From C to E
8. From L to M	18. From L to E
9. From H to E	19. From C to L
10. From H to C	20. From L to C

If our readers will examine the above list carefully, they will see that the twenty changes listed are all the changes possible.

When we consider the many things which happen in the world about us, it is possible to identify many occurrences with one or another of the twenty energy changes in our list. Some of the changes are met with more frequently than others. Some are very rare indeed. It is interesting to see if an example may be found for each one of the changes listed. Here is a partial list of such examples. Perhaps our readers may care to complete the list and to improve upon it.

Until we learn the secret of utilizing directly the energy of the sun, the wind, and the waves, or devise a way to use the warm and cold waters of the ocean in creating power, we shall have to get our heat by the old, old method of burning fuel. Below we see the three rapidly diminishing stand-bys of the world coal, oil, and wood -in the process of being converted to man's use.

What Happens	*The Kind of Energy Change*
1. Rubbing hands together so as to warm them. .	From M to H
2. Turning a dynamo so as to generate electricity	From M to E
3. Can you find an example?	From M to C
4. Striking a poker against a rock so as to cause sparks to fly	From M to L
5. Burning coal so as to drive a locomotive. . . .	From H to M
6. Supplying electricity to an electric motor, so as to make it turn	From E to M
7. Burning gasoline so as to drive an automobile. . .	From C to M
8. Can you find an example?	From L to M

9. Heating the contact point between a strip of iron and one of copper, so as to start a flow of electricity in both....... From H to E
10. Is the cooking of food an example of this change?. From H to C

Photos by International News Photos

A California inventor and his father believe that they have at last devised a scheme for making direct use of sunshine. The picture shows one view of their arrangement of powerful mirrors and lenses which concentrate sunbeams on a spot, there quickly to raise the temperature of water to its boiling point.

11. Heating a metal rod until it glows............... From H to L
12. Sending electricity through an electric heating iron............... From E to H
13. Burning coal so as to heat a stove.......... From C to H
14. Warming an object by placing it in the sun... . From L to H
15. Charging a storage battery by supplying it with electrical energy........ From E to C
16. Sending electrical energy into a lamp so as to light it................ From E to L
17. Using the chemical energy in a battery to yield electrical energy........ From C to E
18. Operating the photoelectric cell in a television set............... From L to E
19. The light which one gets from a burning match... From C to L
20. The effect of light falling on the sensitive chemicals of a photographic film.................. From L to C

If we follow a series of energy changes long enough, we are likely to end with energy in its heat form. That is what happens in the case of most of the sunlight which falls upon the earth. Even that part of it which plants absorb and change into chemical energy finds its way into the bodies of animals. There the chemical energy becomes heat energy for bodily warmth and mechanical energy for bodily motion; but mechanical energy, too, becomes heat energy whenever the body moves. Of course, not all plants are eaten by animals. Those that are not, die in time and the remains slowly decay. The process of decay is one in which most of the chemical energy changes into heat.

Two questions come to mind at once. First, does heat energy ever change into other forms? And second, will there ever come a time when all the energy in the universe has turned into heat energy?

As for the first question, the answer is, "Yes, heat energy does change into other forms." We have already given several examples of such energy changes. However, the change is more or less difficult to bring about. Furthermore, the change is never quite complete. Thus, in driving a locomotive with the heat energy extracted from burning coal, we change less than 10 per cent of the heat energy into movement. The remaining 90 per cent is wasted so far as moving the train is concerned; it goes to heat the air.

Will the Universe Run Down?

Similarly, when the filament in an electric lamp is heated so that it glows, most of the heat caused by the flow of current remains

as heat. About 10 per cent or less changes into light. When our electric lighting bill, at the end of a month, asks us to pay $3.00, about $2.90 is actually for heating the rooms in which the lamps were used. About ten cents represents the amount of light received. Nevertheless, we pay the entire $3.00 and charge it all up to lighting.

As for the second question—as to whether there will ever come a time when all the energy in the universe is heat energy--there is some difference of opinion among the leading scientists of the world. Until quite recently, the answer was "Yes, such a time will surely come." Scientists who studied the matter carefully were and some still are ready to say that when all the energy is heat energy, the universe will be entirely and completely dead. They use the expressions, "The universe is running down" and "The ultimate heat death" to convey the idea that heat energy is becoming less and less available for the activities of mankind and for life of any kind. They point to the fact, which is certainly true, that in every one of the twenty possible energy changes, more or less heat energy is produced as an unusable by-product. One might say that a kind of heat tax must be paid whenever energy changes from one form into another. One can readily see that this tax cannot continue forever without all the energy in the universe becoming energy in its heat form.

However, a difference of opinion has arisen concerning the final fate of the universe. The great American scientist Robert A. Millikan is the leader of an important group of men who believe there is some evidence which points to the fact that forms of energy more available than heat energy are constantly being built up in distant space among stars. We cannot at this point explain this evidence; we can only say that it has to do with the "cosmic rays." These rays have been carefully studied by Millikan and other scientists. It is not yet known what causes them or what they are. They seem to be like X rays, only much more penetrating, and they seem to come continually from every direction in space. If Millikan is correct, the cosmic rays are the "birth cries" which reach us from space whenever matter and energy are changed into forms more available than is heat energy. All over the world scientists are now hard at work checking Millikan's experiments and performing others of their own. Already some of their results throw some doubt on Millikan's beliefs. We shall have to wait for the truth.

The Two Laws of Energy Change

Now there are two laws of energy change. The first of these laws we have already considered. It is called the Law of the Conservation of Energy, and states that energy can neither be created nor destroyed.

Recent discoveries concerning the nature of matter have changed our ideas of matter and energy somewhat. It has been shown that, under certain conditions, matter may actually disappear and in its place a certain amount of energy appear. This is what takes place on a grand scale when energy is released from the nucleus of the atom. Scientists are also reasonably sure that under special circumstances matter can be turned into energy. To be correct, then, we must modify our statement of the Law of Conservation of Energy. We restate it this way: The total quantity of matter and energy in the universe always remains the same. When we state the law in this way we realize that matter can be changed into energy or energy into matter, but that the sum total of the two taken together is always the same.

To date, it is only in a machine known as a cyclotron (sī'klō-trŏn), in atomic explosions, and in the interior of the sun that matter can be readily turned into energy. As yet we have not been able to make large amounts of matter of all types disappear and as a result release energy. So for everyday use, we still hold to the old Law of Conservation of Energy, which states that energy can neither be created nor destroyed.

The second Law says that when energy changes its form, some of it turns into heat energy that is unavailable for the activities of life. This second law of energy change, as we have seen, predicts a "heat death" for the universe. Not all men of science are as yet willing to accept this belief.

Even if the second energy law is eventually

shown to be true, there are still some hundreds of thousands of years before the universe "runs down" completely and "dies." That is a fairly long time in which to get ready for the end of all things. What can man do now to conserve the energy that is still available? Where is this energy?

Not many people worry their heads about the answer to this question; yet each year sees a growing interest in it. One of the important reasons for this interest is the fact that the world's supply of coal and oil is being used up. It seems likely that in another thousand years or so our coal mines and our petroleum wells will be exhausted. When that time comes what shall we use to run our steam engines, our factories, and our automobiles? How shall we keep warm?

The first answer that comes to mind is that we shall use the sun. The sun will still shine a thousand years from now; at least, we have no reason to believe that it will not. But here we face a great difficulty; for we do not know how to make use of the sun's energy efficiently. We seem to use the sun only indirectly. We depend upon plant life to catch this energy for us. After all, as we have seen, coal is the remains of ancient plant life. Oil, too, may be shown to be the result of ancient sunshine. In using up this inheritance from the past we are doing very little to accumulate a supply of fuel for those who are to come after us. Even our present-day forests are being exhausted. So future generations cannot hope for so much as we have received from the past.

Putting Wind, Wave, and Tide to Work

There are many men of science who realize this very grave danger and have been experimenting in many ways with methods of using the sun's energy directly and efficiently. It may be of interest to our readers to learn about some of these efforts.

First, we must mention the attempt to gather in the sun's rays with huge lenses and mirrors. This would be very helpful indeed were it not for the fact that so little of the sunlight can be caught in this way and also for the fact that cloudy weather so frequently interferes. In general, these experiments have yielded very little.

A more successful attempt has been made in the use of the energy of the wind, of the waves, of the tides, and of falling water. It must be understood that the sun is chiefly responsible for the moving air which we call the wind and for the waterfalls, too, since the heat of the sun evaporates the water which later falls as rain, and the rain water supplies the waterfall. The waves, of course, are caused by the wind, and the tides are the result of the gravitational attraction of the sun and moon.

In the case of water power, great progress has been made; but there does not seem to be enough of this energy to supply all of our needs. Wind power, also, fails in the same way, though a number of very interesting wind engines have been invented. Wave motors and tide motors are still in the experimental stage. Great fortunes await the inventors who can find a way of putting to efficient use the energy of wind, wave, and tide. Most of it is now going to waste.

Tapping the Heat in the Earth

If we should fail in all the attempts mentioned above, where else can we turn? It has been suggested that the heat of the interior of the earth might be used when our supply of oil and coal gives out. Certainly the earth contains vast stores of heat energy at high temperatures; but the task of digging down far enough to get at it seems to be greater than human beings can accomplish with the means they now have.

One hope remains. If we cannot leave to future generations as much available energy as we ourselves received from the past, we can certainly leave behind us more knowledge than we received. Knowledge is not energy; but it may prove to be the means of leading the way toward new sources of energy.

Already we have begun to unlock the unlimited energy within the nucleus of the atom. We must realize, however, that most materials cannot be made to yield this energy. Uranium and thorium (thō'rĭ-ŭm) are the principle elements from which we get nuclear energy. Some day, however, the time may come when man can at will release the energy from a grain of sand, a piece of wood, or a drop of water.

PHYSICS

Reading Unit No. 10

ARE ATOMS AND MOLECULES REAL?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What are atoms made of? 1-354

Why are molecules invisible? 1-354-55

What is the difference between atoms and molecules? 1-357

What is an element? 1-357

What is a compound? 1-357

What is the size of a molecule of water? 1-357

What is meant by surface tension? 1-359

Which molecules move the most rapidly? 1-359

Things to Think About

Why do objects keep their shape?

How do molecular conditions explain the different forms of matter?

How do molecules explain the properties of matter?

How may oil be used to calm the sea around a ship?

Picture Hunt

What is the source of the energy used for freezing cakes of ice? 1-356

How were molecular movements first seen? 1-358

Related Material

How are molecules formed from atoms? 1-543-45

How is the speed of molecules measured? 1-389-90

What is found in all atoms? 1-2

What did Democritus, the ancient Greek philosopher, propose as the basis of all matter? 1-281, 532, 13-2

Is the atom a source of energy? 1-352

How did matter develop from the atom? 1-2

How may atoms be smashed? 1-540, 541, 542, 546, 558A

How are the different forms of energy related to molecules and atoms? 1-349, 351

Practical Applications

How is it possible to shape metal? 1-361

How is our knowledge of atoms and molecules applied in industry? 1-356

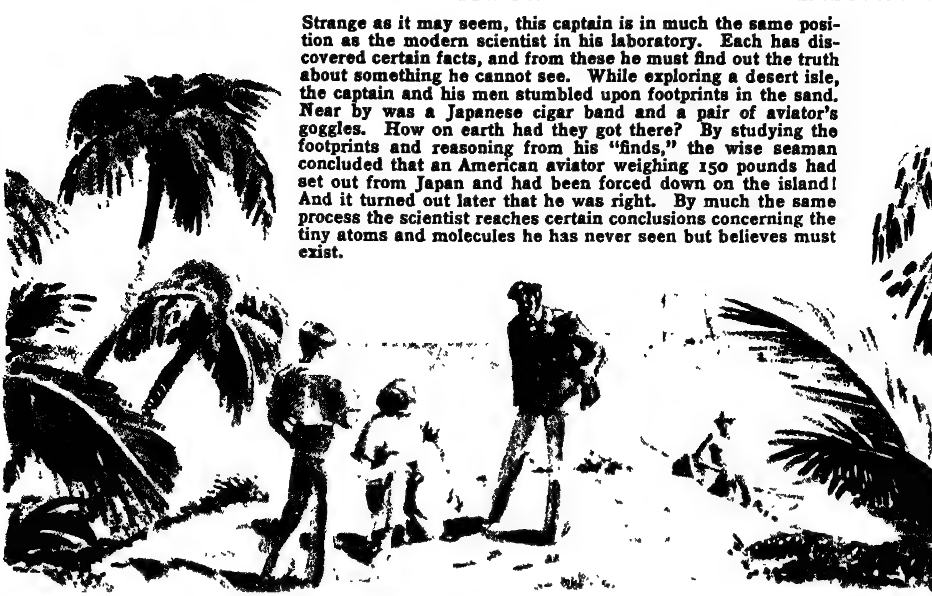
Leisure-time Activities

PROJECT NO. 1: To prove the fact that surface tension exists float razor blades or needles on the surface of a pan of water, 1-360.

PROJECT NO. 2: Show Brownian movements under the microscope, 1-357.

Summary Statement

Scientists can explain many things in nature only by assuming the existence of molecules and atoms.



Strange as it may seem, this captain is in much the same position as the modern scientist in his laboratory. Each has discovered certain facts, and from these he must find out the truth about something he cannot see. While exploring a desert isle, the captain and his men stumbled upon footprints in the sand. Near by was a Japanese cigar band and a pair of aviator's goggles. How on earth had they got there? By studying the footprints and reasoning from his "finds," the wise seaman concluded that an American aviator weighing 150 pounds had set out from Japan and had been forced down on the island! And it turned out later that he was right. By much the same process the scientist reaches certain conclusions concerning the tiny atoms and molecules he has never seen but believes must exist.

ARE ATOMS *and* MOLECULES REAL?

'Seeing Is Believing," We Say; but We Must Believe Many Things That We Can Never Hope to See

THE difference between a solid and a liquid," said the teacher of science to his class, "is that the molecules (mŏl'ē-kūl) in a liquid are further apart and are freer to move about. When a liquid evaporates to become a gas, the same molecules are still further apart and move, therefore, with still greater freedom."

As is too often the case in the classroom, the pupils listened and made every effort to remember what the teacher said. There was little opportunity for questions because no experiment had been performed; nor did there seem to be any likelihood of an experiment when the teacher chose to conclude the period with the above-quoted statement. It was clear that the class was expected to accept the idea as true.

But on the way home from school that day, this interesting conversation took place between two of the pupils:

"Do you really believe that substances are composed of molecules?"

"Certainly. Didn't you hear Mr. Brown say so. Besides, the textbook says so, too."

"I know; but do you really *believe* it? Mr. Brown himself once told us never to believe in things unless they are proved. He said we must always insist upon evidence, upon facts. Yet what evidence did he or the textbook give us that there *are* such things as molecules? It seems to me that they are taking a lot for granted."

"Not at all. All modern scientists believe in molecules and in atoms too. Atoms are even smaller than molecules. Furthermore, atoms are themselves composed of smaller particles, called electrons and protons. If these ideas are good enough for men like Millikan and Einstein, they are good enough for me."

"Perhaps you are right; but I have always liked to see things with my own eyes. The other day I looked at a drop of water under my father's microscope. I could see ever so many things that were invisible to the naked

eye. When I asked my father whether he had a lens that could let me see a molecule of water, he laughed and said, 'No microscope has ever been built that can let you see anything so small as that.' I was going to ask him a lot of questions; but he was too busy. He told me to talk it over with my science teacher. Now I've been bothering Mr. Brown a lot, lately; and it may be that my doubts about molecules are a little silly. But I wish someone would tell me why we can never *see* a molecule and why we believe in them if we can't see them."

Are Molecules Real?

"My advice to you is to forget it. There is a test coming next week; and if Mr. Brown asks about molecules and atoms, I shall certainly write as if I were sure of their existence. You'd better do the same."

Which of the two pupils was right about whether molecules do or do not exist? It is somewhat difficult to say. We, too, believe that atoms, molecules, electrons, and protons are real; but not for the reasons given by the pupil who was eager only to pass the teacher's test. The fact of the matter is that seeing is only one method by which we arrive at the truth. Most of the time it is a sure method; but occasionally even seeing leads us into error and to false conclusions. Let us consider this point somewhat.

We see the sun rise in the east and set in the west; but do we believe that the sun moves around the earth? We believe that the earth is round like a ball; but do we not *see* that the earth is flat? Even though we have never visited the savage tribes in the jungles of Africa, we do not hesitate to believe that there *are* savage tribes and that some of them are cannibals. No one stops to question such facts as that Columbus discovered America in 1492, although no person alive to-day can say that he saw Columbus discover America.

How We Check What We Believe

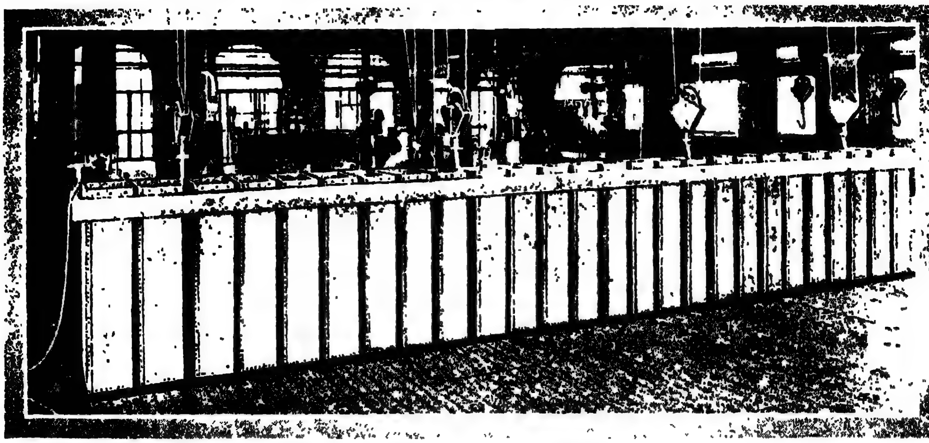
We believe in Columbus and in the existence of cannibals because we rely upon the statements of dependable people who put down in writing what they themselves saw. Their statements have been checked in thousands of ways and found to be correct. When we come to the belief in a ball-like earth that moves about the sun, we rely not upon seeing alone or upon the statements of others, but upon reason that is based upon the things that we and others have seen.

Let us connect all this matter of belief based upon reason in another way. Suppose a theft is committed. A bundle of valuable papers disappears from the top of a desk. The police find that the windows in the room are all latched tightly and that the single door, according to the owner who slept in the room, was not only locked but bolted on the inside. There is no evidence of tampering with either windows or locks; and no finger prints are anywhere to be seen. The investigators note, however, that over the door there is a narrow transom, which was left open for ventilation. The space is too small for any human being to squeeze through. But a close examination of the transom shows a spot where the dust has been wiped clean. And under a small splinter of the wooden framework, a few short hairs are discovered. Experts who examine these hairs explain that they belong to a dog of a certain breed. More careful inspection of the door and transom shows scratches that might have been made by a dog's claws. In the house there lives a neighbor who owns a dog that is noted for his agility and his cleverness in bringing objects to his master. The police seek this neighbor only to find him gone. No one seems to know where he is; and he cannot be found. All conclude that this man is the thief; and a general alarm is sent out.

The Use We Make of Indirect Evidence

Is the man really guilty? The police certainly proceed upon the assumption that he is. When they catch him, they search his belongings. They question him and demand that he explain all his acts before, during, and after the time of the theft. His statements are checked in every particular. In many cases of this kind the investigation ends by the man's confessing his crime.

Now many of our scientific beliefs are very much like the belief in the man's guilt before the confession took place. We depend upon



One may choose not to believe that atoms and molecules are real; but believing that they are has made it possible to understand and control better the workings of nature. For example, in the ice-making plant that is shown in the picture above, water is frozen by energy obtained from burning coal. This apparent impossibility becomes a simple thing to understand if we accept the existence of atoms and molecules.

indirect evidence. We reason about this evidence and set up experiments to check our conclusions. We seldom depend upon mere seeing alone; in these matters it is frequently impossible to see or feel or hear or taste or smell. It is almost always possible, however, to arrange things so that nature's forces produce effects that *can* be seen or heard or felt. Before you turn on the radio, the waves are certainly passing through your body; but you are not aware of their existence. Later, you turn a knob which puts into operation a device that responds to the waves by producing sounds you can hear. You do not see the radio waves; neither do you hear them; but you do hear the effects of the waves upon a machine called a radio receiving set.

Why We Believe in Atoms

Returning now to the conversation between the two pupils, concerning the existence of atoms and molecules, we can say that neither one was correct in his point of view. Atoms and molecules are *real,* even though we can never see them. We do not need to see them in order to believe in them, for we see, hear, feel, taste, and smell the effects which they produce all about us. How do we know that it is atoms and molecules which produce these effects? Because these effects cannot be explained satisfactorily in any other way. Refuse to accept the existence of atoms and molecules and the world of nature—Nature's way of doing things—becomes a confused jumble of meaningless occurrences. You cannot explain simply and satisfyingly how iron rusts or how lead melts; how liquids rise in the stems of plants or how certain clouds give up their rain; how lightning strikes or how things decay; how metals may be extracted from their ores or how automobiles are moved.

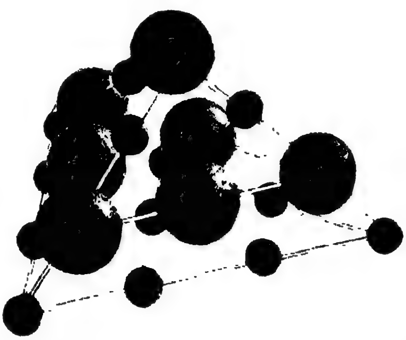
On the other hand, if you accept the belief in the real existence of atoms and molecules, you can not only give reasonable explanations for many of the things which happen in the world about you, but you can control Nature and make her do your bidding. Thus, we have learned to make rustless steel, artificial rubber, and artificial silk. We know how to make liquids boil more readily and how to keep them from boiling. We can freeze water by burning coal; and we can produce rays that enable us to see through a brick wall.

How Atoms and Molecules Differ

And yet the real scientist will say to anyone who doubts the existence of atoms and molecules, "You have a right to your belief; and I am ready at any time to discard my own if without believing in the existence of molecules, you will explain Nature's ways as

well as I can and take advantage of Nature's forces as I can."

Before we attempt to give an answer to this question, it may be well to remind the reader of the distinction between atoms and molecules. In the first place, there are only about ninety-two different kinds of atoms in the entire universe; whereas the number of different molecules are countless. The atoms combine in various ways to form molecules. The atoms may be likened to the letters in the alphabet which number twenty-six. Thousands upon thousands of different words may be formed by combining two or more of the twenty-six letters in various ways. The words are like the molecules. Secondly, the molecules are usually larger than the atoms, and they vary widely in size and in weight. Thirdly, a substance composed entirely of similar atoms is called an "element"; while a substance composed entirely of similar molecules is called a chemical "compound."



It is amazing to learn that scientists have not only estimated the size and mass of particles that cannot be seen by the human eye, but have also calculated the arrangement of these particles. Above, you see a constructed model showing how the atoms in a crystal of salt are arranged. The large balls represent sodium atoms; the smaller ones are chlorine atoms.

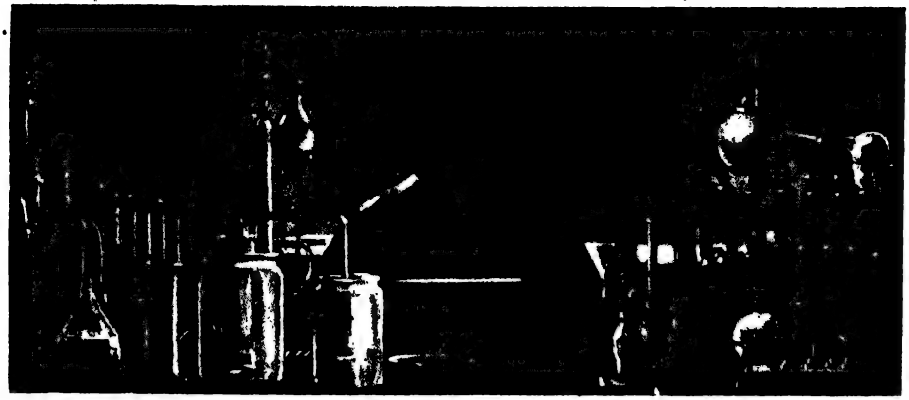
Why Salt Is Called Sodium Chloride

In the substance or chemical compound known as common salt, each molecule contains two atoms: one atom of the element sodium (sō′dĭ-ŭm), and another atom of the element chlorine (klō′rĭn). That is why table salt is referred to as "sodium chloride" (klō′rīd). Now imagine a small cube of crystal salt, about one-half inch high, wide, and thick. How many molecules does it contain? The number is so great that the reader must approach it gradually. In any one of the six surfaces of this salt cube there are about 625 trillion molecules. If each molecule were a brick with a top area of twenty-four square inches, the 625 trillion bricks would more than pave the whole continent of North America. As for the number of molecules of salt within the cube, it would be about 16,000,000,000,000,000,000,000. The best way of reading this number is to call it sixteen billions of trillions.

In the chemical compound known as water the molecules each contain atoms of the elements hydrogen (hī′drō-jĕn) and oxygen. If the water is in the gaseous state, as in steam, each molecule is composed of two hydrogen atoms and one oxygen atom. In the liquid state, each water molecule may contain as many as eight hydrogen atoms and four oxygen atoms—or even ten hydrogen atoms and five oxygen atoms. How large is a molecule of liquid water? To appreciate the smallness of its size, consider this comparison: Imagine that a water molecule and a baseball each begin to grow larger and larger at the same rate. When the molecule has become as large as the baseball, the baseball has become as large as the earth.

We have to thank two men for showing us how we can almost see molecules. The first was Robert Brown. More than a century ago he applied a powerful microscope to a liquid in which were suspended a great many tiny drops of oil. The oil drops were so fine that even through the microscope one could barely see them. Yet each drop contained fifty million molecules of oil. But the interesting thing was that each drop, instead of floating quietly about, seemed agitated. It bobbed this way and that, as if someone or something were bumping into it with great force. Dr. Brown explained the sudden, jerky movements of the oil drops by saying that rapidly moving water molecules were banging into them, now from this side, now from that. His explanation has been accepted as true.

Zsigmondy was the second of the two men who showed a way of studying the effect of molecular (mō-lĕk′ū-lár) movement upon other small particles. His experiment was superior to that of Dr. Brown in that he invented a more powerful microscope. He



Zsigmondy directed a strong beam of light at a suspension of very fine particles of gold. Ordinarily, these specks of gold are too tiny to be seen even with a microscope; but when they are made to reflect a strong beam of light, the small specks become visible under a powerful microscope. In this way Zsigmondy came as near as possible to seeing a molecule. Each particle was composed of a few dozen molecules.

suspended very fine gold dust in a jar of water. The particles of gold were far too small to be seen by the ordinary microscope, for they each contained but a few dozen molecules of gold. In order to see such small particles, he directed a powerful beam of light at the suspension. Just as invisible dust particles in the air become visible when a sunbeam strikes them, so these tiny gold particles became visible through a microscope when the strong beam struck them. Each particle reflected some of the light to the observer's eye. When a rapidly moving water molecule collided with a gold particle, the gold particle shot forward as a result of the collision. To illustrate the effect upon Zsigmondy's gold dust when it was hit by a water molecule we may compare it with what happens to a golf ball driven off a tee. Zsigmondy reports that the gold particle jerked foward so fast when struck by a water molecule that it covered a distance more than 1,000 times its diameter in one-sixth of a second. When the water molecule hit the oil drop, it was more as if the golf club had struck, not the golf ball, but a heavy stone.

The Illusion of Stillness of Bodies

It is clear from the experiments of Brown, Zsigmondy, and others that molecules move. In fact, they are never at rest. The apparent quiet of objects that seem never to move is an illusion. Within the motionless table or the fixed girder that supports a building, the molecules are vibrating fiercely back and forth. In liquids this motion is even greater; and in gases the molecules dart here and there with speeds that are seldom reached in the world of larger bodies.

Can We Stop the Dance of the Molecules?

One of the important ideas in science— we shall have occasion to say more about it in a later chapter—is that the heat energy which a body possesses is actually the mechanical energy of its molecules. Thus, the faster the molecules move, the hotter is the body. Presumably one may cool an object to a temperature so low that its molecules stop moving. Nothing could be colder than that; and so this lowest possible temperature is called "absolute zero." Man has never been able to make things quite so cold as that. Certainly no place on earth, even at the Poles, is so cold as absolute zero, which is about 491° Fahrenheit colder than the temperature of freezing water. In recent years improved methods of refrigeration have been devised by which objects are cooled to within a fraction of a degree of absolute zero. At such a temperature the dance of the molecules has almost, but not quite, ceased.

It is amazing to learn that scientists have not only estimated the size and mass of particles that cannot be seen by the human eye, but they have also measured the speed of these particles. The method employed is not difficult to understand. In the case of gases, as we have seen, the molecules travel very rapidly. In a room the molecules of air are incessantly smashing into the walls, the ceiling, the floor, the furniture, and against the surface of any human body in the room. This pounding by trillions of molecules causes a steady pressure against the walls and every object in the room. The faster the molecules move, the greater is their combined impact and the greater, therefore, is the pressure. By measuring this pressure, which may be easily done in several ways, we can estimate the molecular speeds of the molecules of a particular gas. It is to be remembered that the speed thus measured is the average speed of all the molecules taken together, rather than the speed of any one molecule.

An understanding of the behavior of molecules helps us to explain this very interesting process of making duplicate copies of a bill of fare in a restaurant. The device above is known as a hectograph.

Like molecules attract each other. Scientists refer to this force of attraction as "cohesion." In the instance shown above, it is the force of cohesion which keeps the molecules of liquid in a stream.

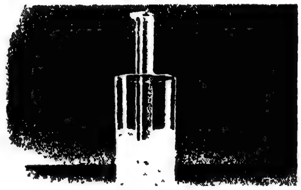
The Great Speed of Hydrogen Molecules

A thimbleful of hydrogen gas, kept at the temperature of freezing water and at a pressure of fifteen pounds to the square inch, weighs about three ten-millionths of an ounce. We know also how many molecules it contains. In order that that many molecules, each weighing what it does, shall cause a pressure of fifteen pounds to the square inch on the surface of the containing vessel, the molecules must move with an average speed of over a mile a second. The swiftest rifle bullet does not travel at so high a speed. In heavier gases than hydrogen, the speed is not so great, because the molecules are heavier. In the case of air molecules, the speed is about seventeen miles a minute, which is four times faster than the fastest airplane yet built.

Why Objects Keep Their Shape

The very fact that objects exist apart from other objects, indicates that some molecules keep together, resisting any effort to tear them apart. It is easier to cut wood than stone because the molecules in stone attract each other with greater force than do the molecules in wood. If it were not for this attraction among molecules, a book lying on the table might soon disappear, its molecules mingling with those of the table and the air.

When unlike molecules attract each other, the force is called "adhesion." In a narrow, hollow tube immersed in water, the liquid climbs to a higher level wherever it touches the tube. This effect is known as "capillarity."



Here the liquid is mercury. The molecules of mercury repel, rather than attract, the molecules of glass. That is, capillarity depresses the surface of the mercury wherever the mercury touches the glass.

When a molecule of water attracts a molecule of water, we refer to the force of attraction as one of "cohesion" (kō-hē′zhŭn); that is, like molecules of any kind cohere (kō′hēr′). When a postage stamp is fixed to an envelope, the force of attraction between the molecules of glue and the molecules of paper is called "adhesion" (ăd-hē′zhŭn); that is, unlike molecules sometimes adhere (ăd-hēr′).

Inserting an object in water usually wets the object because the adhesion of water molecules for the molecules of the object is greater than is the force of cohesion among the water molecules themselves. Some

liquids, like mercury, have so great a cohesion among their molecules that they do not wet certain objects placed in them. So one may insert a finger into a dish of mercury and bring the finger out dry.

An interesting effect is observed if an open glass tube is inserted in a dish of water. The glass molecules attract the water molecules, so that the cohesion among the water molecules is overcome to some extent. The water climbs up on the glass both inside and outside of the tube. The narrower the tube, the higher is the climb within. In such a case, the force of adhesion seems to be greater than the force of gravity. Much of the rise of liquids in the stem of a plant and the trunk and branches of a tree may be explained by this force of adhesion. The force is often referred to as capillarity (kăp'ĭ-lăr'ĭ-tĭ).

When a similar glass tube is inserted in a dish of mercury the effect is different. The level of the mercury is depressed both inside the tube and at the point of contact outside. Here, the molecules of glass seem to repel those of the mercury. Really the cohesive force in the mercury is greater than the adhesive force between glass and mercury. Again the narrower the tube, the greater the depression.

This boy is pleased because he succeeded in making a steel needle float on water. Perhaps he understands about the cohesion between molecules at the surface of a liquid. It produces a "surface tension" strong enough to support the needle, provided that the surface is not pricked.

Why a Needle Will Float on Water

The forces of cohesion and adhesion explain many things that happen in the world about us. Paint, for example, sticks to the surface to which it is applied because of adhesion. Sand, applied like paint, falls off immediately because the force of cohesion in this case is greater than that of adhesion. One cannot lift a lump of water out of a dish because the force of gravity is greater than the cohesion among the water molecules and as a result the water spills out from the hand. In the case of jelly or of mud, one can lift a good deal of it in lumps because the force of cohesion is greater than that of gravity.

Now let us consider the molecules in a dish of water. At all points beneath the surface each molecule is being attracted by others in all directions. A molecule at the surface, however, is being attracted by those beneath and by those to the left and right. There are none to pull it upward from above. This results in a tension at the surface which tends to resist any force that tries to break through. A needle, or even a razor blade, may be floated on the surface of water, in spite of the fact that steel ordinarily sinks quickly. We urge the reader to try the experiment of floating a needle on water. Lay it on very gently, so as not to break through the surface tension.

Surface tension also explains why soap bubbles may be blown. The soap and glycerin which are added to the water increase the cohesion among the molecules of the solution. When a raindrop falls freely through the air, its shape is almost that of a sphere because the surface tension pulling inward in all directions tends to force the drop of water to huddle together into the smallest possible volume - which is a sphere. Taking advantage of surface tension, the manufacturer lets molten lead fall through the air for some distance, with the result that the liquid lead forms into small balls. These have hardened by the time they hit bottom, and so have become lead shot. Oil spread on waves tends to calm them; for the oil film spreads easily over the water and increases the surface tension. The same action is often observed when oil is added to water to keep the water from boiling too violently.

Liquids have the power of mixing with each other when they are perfectly still,

with nothing to stir them or create currents in them. This gradual mixing of the molecules of two unlike substances—such as air and water or alcohol and water—is known as "diffusion." Liquids will mix even when there is a porous membrane, such as a piece of bladder or parchment, between them. They will even mix through a piece of porous pottery. The process by which they pass through the substance that separates them is known as "osmosis" (ŏs-mō'sĭs).

An Interesting Experiment

When two unlike liquids, such as water and glycerin or pure water and salt water, are separated by a porous substance, each liquid will pass through the separating wall, but one is likely to go through at a greater speed than the other. Water, for instance, will pass into glycerin faster than glycerin into water. So if the two liquids are put side by side in a jar with a membrane between them, the level of the water will sink and the level of the glycerin will rise.

You may yourself perform an interesting experiment in osmosis. Fill a glass jar with water and in it suspend a piece of parchment which you have drawn up into the shape of a sack. Fill your little sack with grape juice and tie it securely, making sure that none of the grape juice can escape over the edges of the parchment. You may watch it gradually seep through the parchment into the water.

Secrets Shown by X Rays

It is only in recent years that scientists have been able to examine the manner in which molecules arrange themselves within a substance. As one may well imagine, molecular arrangement cannot be studied with the naked eye, or even with a microscope. The structure of matter was a great mystery until the X ray was discovered. With it one may penetrate deep into a steel casting and take pictures of what is happening within the metal. The knowledge which these pictures bring to those who can interpret their meaning has thrown light on the behavior of matter—which otherwise is quite mysterious.

Why, for example, do some materials absorb water like blotting paper while others keep it out? Why may some substances be easily compressed or expanded while others cannot be squeezed into smaller volume except by exerting tremendous force? Why is diamond hard and coal soft, even though the two substances are both composed of molecules of carbon? Why is a steel wire tougher —or more tenacious (tē-nā'shŭs)—than one of lead? Why does a rubber band stretch? Why may a lump of gold be beaten into a sheet so thin that it is transparent to light while other metals break up when one tries to beat them thin? Why is copper softer than iron? And why are some metals suitable for wires while others soon break when one tries to draw them out into threads?

What Are the "Properties of Matter?"

In all of these questions we have been pointing to different "properties of matter." Porosity (pō-rŏs'ĭ-tĭ), compressibility, expansibility, hardness, tenacity (tē-năs'ĭ-tĭ), elasticity (ē'lăs-tĭs'ĭ-tĭ), malleability (măl'ē-ȧ-bĭl'ĭ-tĭ), and ductility (dŭk-tĭl'ĭ-tĭ) are properties of matter—each one illustrated in its proper order above—which we observe and make use of in daily life and in industry Greater understanding of how and why matter possesses these properties has made possible many of the comforts and conveniences of civilized life. This increased and better understanding has come through the study of how molecules arrange themselves.

We opened this chapter with a statement made by a teacher of science to his class. Read this statement again. It may have more meaning to you now. The teacher has explained the difference between the solid state, the liquid state, and the gaseous state in terms of molecular (mō-lĕk'ū-lȧr) arrangement and movement. In a later chapter we shall return to these important states of matter and study how a change from one state to another may take place.

Perhaps our readers are now in a better position to understand why scientists *must* believe that atoms and molecules really exist, although these amazing particles will forever be invisible to human eyes.

PHYSICS

Reading Unit
No. 11

HOW WE PUT LIQUIDS TO WORK

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How may water be made to carry an electric current? 1 363
What is water made of? 1–363
What are the properties of hydrogen? 1–363
What are the properties of oxygen? 1-363
Is there water in solid granite? 1 364
Where does water exert a pressure of five tons per square inch? 1–365-66
What causes water to flow? 1 369
How may water be put to work? 1 369-70

Things to Think About

How does water pressure increase with depth?
Why cannot divers descend more than several hundred feet below the surface of the ocean?
How may a fast-flowing river be controlled?
How may water be decomposed—or taken apart?

Picture Hunt

How much water is there on the earth? 1–363
How may ten pounds be made to move ninety pounds? 1 368

Related Material

How are products packed by means of liquid pressure? 13–256
How is gold mined with the aid of water pressure? 9–391
What was the water supply of primitive peoples? 10–548
How did the Romans supply their cities with water? 10-546, 548-49
How does man build tunnels under water? 10-205-7
How much water is there in the human body? 2-420
How does impure water affect health? 10 551

Practical Applications

How may a farmhouse be supplied with running water? 1–369
How are heavy weights lifted by means of water? 1-368
How may the energy of flowing water be harnessed? 1 369-70
How may liquids be used to measure pressure? 1-367

Leisure-time Activities

PROJECT NO. 1: Decompose—or take apart—water with the aid of dry-cell batteries. 1–364.

Summary Statement

Because water has weight, it exerts a pressure on the vessel that contains it. This pressure can make water do work.

If all the water on the earth could be gathered together, it would make a ball about 850 miles in diameter. You can see from the picture that our 850-mile ball of water seems rather small in comparison with the ball that is the earth, for the earth is nearly 8,000 miles in diameter. But it is this seemingly small amount of water which makes life possible on earth. It was in the ocean that life first developed.

The water spreads out so as to cover three-quarters of the earth's surface, forming oceans that are more than five miles deep in certain places. Because of water, great areas of land have sunk and others have risen, plains have been heaved up into mountains and rugged mountains have been worn away until they are gently sloping hills. Water grinds rock into sand and lays sand down in layers, later to become rock.

HOW WE PUT LIQUIDS TO WORK

Water, the Most Interesting Liquid on Earth, Is Necessary for Life and for Many of the Activities of Mankind

"NOW! Are the wires all connected?"

"Yes, everything is ready."

"Are the test tubes in place?"

"Certainly; they are filled with water and the open ends are submerged, just over the platinum terminals."

"All right, snap on the switch and watch for the hydrogen and oxygen."

A sharp click sounded in response to the last command, but nothing happened. The tubes, the water, the wires, and the terminals remained exactly as before.

"Something is wrong! Did we forget anything?"

"If we did, I can't see what it is."

"By the way, did you put a bit of acid in the water?"

"No. Why do we need to do that?"

"Because water does not conduct electricity unless it has salt or acid dissolved in it."

"Very well. Here is the salt!"

The switch clicked again and the two experimenters were rewarded in obtaining an immediate reaction. Two streams of bubbles began to flow upward from the terminals. The gas collected at the upper, closed ends of the test tubes. As the gas increased in volume, more and more of the water originally in the tubes was pushed down into the dish. In one tube, however, about twice as much gas gathered as in the other.

"There," said one of the experimenters, "this larger volume must be hydrogen. The other tube must contain oxygen."

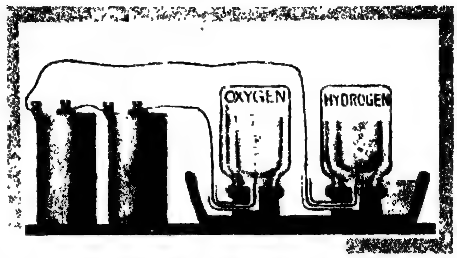
"Yes," was the reply, "we have at last succeeded in breaking up the molecules (mŏl′ĕ-kūl) of water. Instead of molecules, we now have the atoms of which the molecules are composed. Judging from the fact that we have about twice as much of one gas as of the other, I should say that the textbooks are right when they refer to water as H_2O."

"How can we make certain that the larger amount of gas is hydrogen—that is, H_2—and the smaller amount oxygen—that is, O?"

"That should not be difficult. When the two tubes are full, we can remove them and make the test. Hydrogen, you know, is very inflammable, it burns with a blue flame and explodes violently if mixed with air. Oxygen, on the other hand, does not itself burn; but

it supports the burning of other things that are immersed in it."

In a little while the above tests were applied. A lighted match brought to the mouth of the tube suspected of containing hydrogen, resulted in an explosive pop. Evidently the hydrogen had mixed with the air. A glowing match stick inserted in what was presumably the oxygen, burst into flame and burned violently. The two experimenters put away their apparatus with the somewhat satisfied feeling of having proved that liquid water is composed of two gases, hydrogen and oxygen. It seemed strange, but it was true!



This is one way of breaking molecules of water into atoms of hydrogen and oxygen. The volume of hydrogen formed is always twice as great as the volume of oxygen.

Our readers may wish to try for themselves the experiment of breaking up water with the help of an electric current. One should learn as much as possible about the liquid upon which our lives depend.

How Old Is Water?

Water is one of the oldest things on earth. Ever since the earth cooled down sufficiently to let the rain fall—which, it is believed, may have taken place about a hundred million years ago—the oceans have bathed the continents. If all the water that exists to-day could be gathered together, it would make a ball about 850 miles in diameter. In the oceans life first developed. Because of water, whole continents have sunk and others have risen, plains have been heaved up into mountains and rugged mountains have been worn away until they are gently sloping hills. Water grinds rock into sand and packs sand into rock.

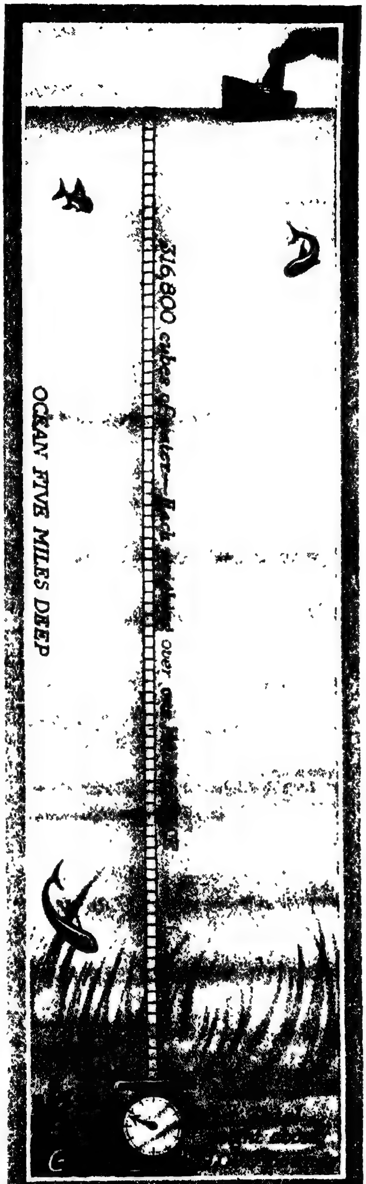
The oceans spread over three-quarters of the earth's surface to an average depth of about two or three miles. In certain places the depth is more than five miles. They keep the air supplied with moisture and make possible the growth of plants. They are responsible for most of the weather conditions. Water finds its way into the soil and into nearly every substance of the earth's crust. Even rocks contain water. It is believed that nearly two gallons might be extracted from a cubic yard of certain kinds of granite. Were it not for water every pebble, every grain of sand which now lies loose on the ground, would continue to lie there through untold ages, unchanged and unmoved. Every twenty-four hours the human body throws out from skin and lungs nearly two pounds of water. The food we eat is chiefly water and our bodies, therefore, are at least three-fourths water. Without water we could not bend a muscle or feel through a nerve. Even the bones of our bodies are built up by means of water.

Water means change and change means life. Yet water itself has changed very little through the ages. The very molecules which wet our bodies as we dive into the surf may have washed the skin of a giant dinosaur a million years ago. True, certain particular molecules may in the centuries past have wandered from place to place and from one substance to another. In imagination we can think of a water molecule drawn up by the sun from the ocean into the air, where it forms part of a cloud. Later it falls as rain, seeps into the soil, becomes part of a growing plant, is eaten by an animal, and is thrown off again into the air. Continuing its wanderings, the molecule finds itself frozen in an iceberg floating in the sea. Again it melts and evaporates, only to fall as rain again upon the ground. This time it may be part of a city's water supply used to wash away sewage. Leaving filth and bacteria behind it travels to the air, where it is sucked in by the carburetor of a passing airplane. Sometime later the same molecule finds itself frozen in an ice cube of a modern refrigerator, and later still it is one of many molecules that make a radiator hot or that move the piston of a steam engine. And once the molecule was part of a man's brain. On it goes, in its ceaseless round,

always remaining the same. As a molecule of water, it is composed of two atoms of hydrogen and one of oxygen—it is H_2O, just as it was a million years ago.

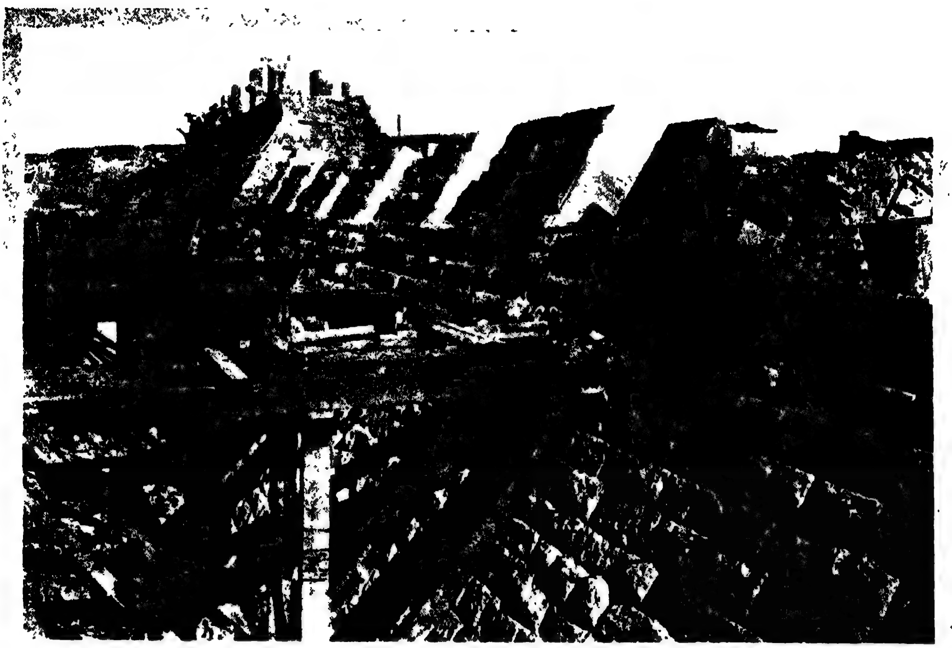
We do not know with certainty whether other planets and stars have been blessed with water; but we do know that life such as ours could not exist without this precious substance. We have only to study the moon to see what would happen to us should water disappear from the surface of the earth. Death would reign everywhere. Silence and stillness would take the place of all life, movement, and change.

If you have ever had to fetch a pail of water, you will recall that liquid water is by no means a light substance. The force of gravity upon it is considerable. One cubic foot of it weighs about sixty-two pounds. A cubic inch of water weighs a little more than half an ounce. If one were to pile twelve such cubes one on top of another, the combined weight would be eight ounces, or half a pound. Now think of a square inch of area at the bottom of the ocean where the water is five miles deep. On this area one might pile a column of one-inch water cubes reaching up to the surface. Furthermore, the distance of five miles would permit the piling of 316,800 of the cubes. Their combined weight, resting on an area of one square inch, would be 176,000 ounces, which is 11,000 pounds, or nearly 5 tons. Thus, the weight of water in the ocean at a depth of five miles exerts a pressure of at least five tons on every square inch of the ocean bottom.



Imagine scales placed at the bottom of an ocean five miles deep. In five miles there are 316,800 inches; so 316,800 inch-cubes of water may be placed on the scales. Since each cubic inch of water weighs more than half an ounce, the entire column will weigh about 11,000 pounds. Thus, the pressure at the bottom of the ocean five miles deep is about 11,000 pounds on every square inch of surface.

Some years ago a United States naval expedition set out to survey certain parts of the ocean bottom. In the course of measurement, officers lowered into the water several hollow glass globes. The walls of these globes were thick, and not even a microscope could detect an opening or a pore in them. Yet when the balls were raised from the depths, water was discovered inside. How did the water get in? The only possible explanation is that the tremendous pressure five miles below the surface forced molecules of water through the invisible tiny spaces between the glass molecules. Another interesting experience of this expedition was in connection with fish brought up from great depths. No sooner did the creatures come to the surface than they exploded. Living their lives where they had to endure terrific pressure from outside, these marine animals have adapted themselves to the conditions in which they live. Their bodies grow in such a way as to withstand terrific squeezing; their internal bodily fluids press outward with a force equal to the inward pressure. But when they are brought suddenly to the surface, the outside pressure vanishes; and then their bodies explode.



When a dam is built across a river, the water piles up behind it to a great height. The deeper the water, the greater is the pressure at the bottom of the river. That is why the bottom of a dam must be thicker than the top. This difference in thickness is shown in our picture of the Aswan Dam, in Egypt, in course of construction. That great dam across the Nile is one of the most famous in the world.

In speaking of pressures exerted by fluids, the man of science uses the expression, "so many pounds per square inch." Thus, he distinguishes between the pressure upon any area and the "total pressure" upon that area. For example, a square inch of surface at a depth of five miles supports a "pressure" of more than five tons. So does a square foot or a square mile, for that matter. However, the "total pressure" on these areas is different in each case. It is five tons on one square inch, but 144 times 5 tons on a square foot, since a square foot contains 144 square inches. When one dives into water to a depth of ten feet, the added pressure of the water on the body is about five pounds per square inch. That does not seem like very much; but the "total pressure" is exceedingly great. Assuming that your body has a surface area of 2,000 square inches, the 5 pounds per square inch mean a total pressure of 5 times 2,000, or 10,000 pounds.

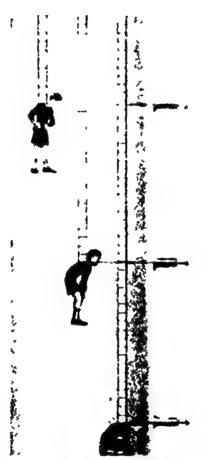
From all that has been said above, it is clear that the further down under water one goes, the greater is the pressure. We are often cautioned against diving too deep, because the water pressure may injure the eardrums. When a dam is built, the bottom of the retaining wall is the thickest part of it, since the greatest pressure is exerted at the greatest depth. As it nears the top, the retaining wall may become thinner. At the very top the wall may be very thin indeed, no matter how large the expanse of water retained.

Why We Cannot Go Deep under Water

There is a limit to which man may descend into water. When tunnels are bored under water or foundations for bridge towers are built, the workmen are incased in large domes or caissons (kā'sŏn)—which are nothing but water-tight boxes—from which the water is pushed out with air pressure. The extent of this pressure depends upon the depth of water overhead. A river 100 feet deep adds a pressure of about 50 pounds per square inch to the air

which the workmen must breathe. A depth of 200 feet adds about 100 pounds per square inch. This is true for submarines and for deep-sea divers who descend in diving suits—small caissons—to help raise a sunken ship or salvage a lost treasure. Now the greatest depth to which man has descended in the manner we have just described is 420 feet. This adds about 200 pounds per square inch to the air one must breathe at such a depth. To go deeper makes the strain on the body unbearable and often results in death.

But another method has recently been devised by the naturalist William Beebe. He has built a metal ball large enough to hold him and strong enough to resist the pressure at a depth of 1,426 feet. To that depth he has actually descended. After he enters the ball with his instruments, the trapdoor is screwed down tightly and the strange laboratory is lowered over the side of the ship by means of chains. It is weighted down, to make it sink, and air pumps supply it with fresh air and remove the foul air. The scientist inside keeps in touch with those on board by telephone, and he directs a searchlight through the strong glass window so that he may watch the wonderful forms of life swimming about. Beebe has already descended to a depth of half a mile in the waters off Bermuda. It is to be hoped that he will never go so far down that the water will begin to ooze through the pores of his metal sphere. In steel, as in glass, there are spaces between molecules, and through these spaces water molecules may enter if the pressure is great enough.



Of the three openings in the water tank, the lowest one lets out the water with greatest force, because there the pressure is greatest. If at each opening you had to support a column of inch-cubes of water on your back, the weight at the lowest opening would bend you double.

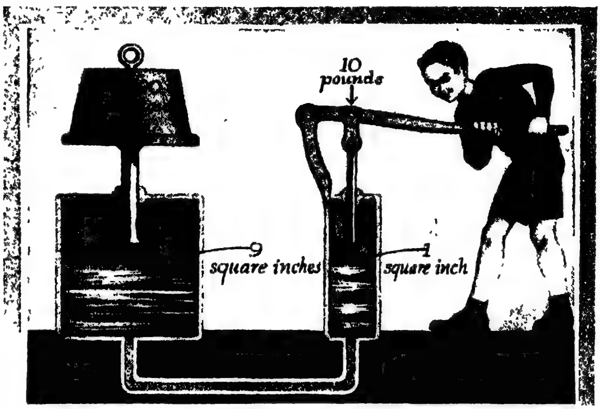
The fact that pressure increases with depth provides a simple means of measuring the pressure exerted by fluids. An interesting experiment will make this clear. Get two long glass tubes and connect them with a six-inch piece of rubber tubing. Arrange the tubes firmly before you in the shape of the letter "U." Now pour some mercury into the tubes, so that the level of the metallic liquid stands about twelve inches high in each arm. Note that mercury, like water, seeks its own level. Through another rubber tube reaching from your mouth to the open end of one of the glass tubes, blow as hard as you can. The mercury level drops on one side and rises on the other. Measuring the vertical distance between the level of the mercury in one arm and that in the other, you can calculate the pressure with which you blow. Just as we showed how a twelve-inch column of water exerts a pressure of one-half a pound per square inch, so it may be shown that a one-inch column of mercury—which is about thirteen times as heavy as water—exerts a pressure of about one-half a pound per square inch. If, therefore, your blowing causes a total difference between levels of ten inches, the force of your blow is ten times one-half, or five pounds per square inch.

Pascal's Experiments with Pressure

Instead of blowing into one side, attach that side to the water faucet and turn on the water. How high up does the mercury go on the other side? If the difference between levels is 22 inches, what pressure does the faucet exert? It will be worth the reader's

while to remember that a one-foot column of water and a one-inch column of mercury each exert a pressure of about one-half pound per square inch.

In the middle of the seventeenth century there lived a French scientist by the name of Pascal (pås'kål'). He was a great student of pressures caused by fluids of various kinds. In the course of one of his experiments he made the observation that fluids behave differently from solids when forces are applied to them. If one pushes forward against a table, one expects to see the table move forward, not backward or to the left or to the right. But when one pushes on a liquid, the pressure is transmitted in all directions with equal force. The reader may satisfy himself that this is so by performing the following experiment: Get an ordinary rubber ball and punch a number of small holes in it. Have one hole at the top, another at the bottom, a third in front, a fourth at the back, a fifth at the left side, and a sixth at the right. Punch several small additional holes at various places. Now squeeze the ball so as to push out the air, and immerse it in a jar of water. As the ball regains its shape, water will fill it. Remove the water-laden ball and set it on the table. Then push the ball sharply with your finger. What happens? The water spurts out in all directions, wherever there is a hole. You probably will duck to keep from getting wet. The interesting fact about the experiment is this: while you exert a push on the water in only *one* direction, the push is transmitted in many directions. If the ball were a sieve, a jet would spurt from every opening. Furthermore, the force of one jet would be the same as any other. That is what Pascal meant when he said that a pressure externally applied to an inclosed fluid is transmitted equally in all directions.



This shows how a hydraulic press works. Since the ten pounds of pressure is applied to an area of one square inch, this force will be transmitted to every square inch of the larger piston. And since the larger piston contains nine square inches, the force is multiplied by nine, resulting in a lift of 90 pounds.

Have you ever wondered how fluffy cotton fibers are packed so tightly in bales?—or how machines can press so hard as to give a desired shape to a sheet of felt, of copper, or of iron? These operations and many others like them are accomplished by a so-called "hydraulic (hī-drôl'ĭk) press," which is a device based upon Pascal's principle. The picture will help you to understand how this press works.

The machine contains two cylinders which connect with each other much as do the two arms of a U-tube. One cylinder is narrow and the other wide. The narrow one contains a piston which may be moved up and down with a pump handle. As a matter of fact, it *is* a pump, which draws liquid from a cistern and forces it into the large cylinder. There, a large piston is forced upward by the incoming liquid. It is moved upward slowly but with tremendous force. A mass of cotton placed upon it will, in time, be squeezed powerfully against the overhead platform.

How the Hydraulic Press Works

The downward push of the small piston is transmitted by the liquid as an upward push of the large piston. Let us assume that the small piston has a cross-sectional area of one square inch, and that the push down on it is equal to ten pounds. An equal pressure upward will then reach the large piston. However, we must not forget

Water from the elevated tank flows down to supply all the floors of the house with water. Which of the two faucets shown in the picture will deliver water with greater force? The lower one, of course.

that the pistons are of different sizes. If the area of the large piston is 100 square inches, the ten-pound pressure is multiplied 100 times. The ratio of the pressures is the same as the ratio of the areas. Thus, a hydraulic press of the dimensions given above will change a downward pressure of ten pounds into an upward pressure of 1,000 pounds.

How Water Seeks Its Own Level

It is a common sight to see water flowing downhill. In a sense, it does so because of its own pressure. Actually, it is the force of gravity which acts on water as it does on all bodies. When unsupported, the water falls. If the drop is not steep, the water flows rather than falls. Should the supporting surface begin to slope upward, the energy of downward motion may carry the water up the incline. Except for friction the water may rise to the same level from which it started. That is the meaning of the expression, "Water seeks its own level."

We take advantage of this fact in supplying water to the inhabitants of large towns and cities. In New York City, for example, about a billion gallons of water are used each day of the year. The water is gathered from lakes and streams and stored in large reservoirs, which are, in some cases, located more than a hundred miles away. The reservoirs are high in the hilly regions of New York State. Because of this elevation, the pressure causes the water to flow through huge passageways, or aqueducts. These stretch for miles over hills, through mountains of rock, and under the wide Hudson River. Finally they reach the city, where they bury themselves five hundred feet beneath the pavement. Shafts reach down to tap the water supply. Pushed by the weight behind it, the water flows up in these shafts to a height which is almost that of the reservoirs in the mountains one hundred miles away.

Of course, many of the buildings in New York City are so tall that the water does not rise to their tops. In such cases the water must be lifted by means of pumps. The action of pumps will be explained in a later chapter.

How the Energy of Flowing Water Is Used

Like many of nature's great forces, the energy of flowing water may at one time be a powerful aid to man and at another time a terrible scource of destruction. Whether it is the one or the other usually depends upon how well he understands the laws of nature and upon how well he can adapt himself to them. In the case of the force

due to flowing water, man has been but partially successful in his understanding and in his adaptation. Now and again we read of a river in flood which destroys lives, wrecks homes, and brings misery and suffering to many families. The Mississippi is an outstanding example in our own country. Millions are being spent to counteract and to divert the energy of moving water when this great river overflows its banks. We are hopeful of final success.

Controlling the Great Colorado

Then there is the raging Colorado River. Here the problem is not so much the controlling of floods as of utilizing the great waste of water and of energy which might be put to good use in a region that is as dry as dust, and needs power so badly. Already, however, the problem has been solved. Hoover Dam is now finished. The turbulent water at the bottom of the Great Canyon has been penned up and allowed to move only when man wants it to move and to flow only where man wishes it to flow. The water thus stored up and under control now irrigates deserts instead of uselessly wearing away rocks. The water pressure piled up in the reservoir moves wheels and turbines to provide energy for farming and for industry. Hoover Dam is a symbol of modern efficiency.

Another great project in which both the United States and Canada are interested is the control of the moving waters of the St. Lawrence River. In this case the aim is neither flood prevention nor irrigation, but the building of a continuous water channel from the Atlantic Ocean to the Great Lakes. Nevertheless engineers find that before this channel can be built, the force of flowing water must be controlled. By permitting this force to do the useful work of driving water turbines, the necessary control is gained and, in addition, a great deal of the cost of the undertaking may be paid.

The power plant at Muscle Shoals, which makes use of the moving water of the Tennessee River, is still another effort in the direction of controlling the flow of water. Our country built the plant during World War I in order to make nitrates for fertilizer and ammunition. Now we are using the energy to make fertilizer only. The farmers use it to grow their crops.

For hundreds of years, perhaps thousands, people have made use of flowing streams to grind their wheat into flour and to saw wood. In the rural districts one occasionally comes across a water wheel that is still performing useful work. Such wheels are of three kinds: the overshot, the undershot, and the breast wheel-- depending upon where on the wheel the force of the water is applied. The more modern types of water wheels are the Pelton and the turbine.

In the case of the Pelton wheel, great pressure is usually employed. The water, therefore, must be collected at a great height. It shoots out of a nozzle and strikes a series of carefully designed blades on a wheel. A great deal of thought and experimentation has been given to the shape of the nozzle and its size, as well as to the exact curves of the blades which the jet of water strikes.

How the Water Turbine Works

The water turbine, which is as efficient as the Pelton wheel, is often used when the elevation of the water is not extremely great but when the amount of water available is large. There are two important parts to a water turbine: the fixed blades, which direct the force of the water, and the movable blades, which spin round to deliver the power. In operation, the water is permitted to flow down through a broad channel, or "penstock," and against the fixed blades. The blades direct the force at the proper angle, so that each blade of the movable wheel gets as powerful a push as possible. The movable wheel turns on a shaft which is also the shaft of a dynamo armature. In this way the energy of moving water is efficiently transformed into electrical energy.

PHYSICS

Reading Unit No. 12

THE WONDERFUL GAS IN WHICH WE LIVE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The stratosphere, 1–372

Why is air invisible? 1–373

Does the sun lose heat to the air? 1–373

When may the earth become like the moon? 1–373

Is air a mixture of gases? 1–373-74, 376

What are the properties of nitrogen? 1–375

What are the properties of carbon dioxide? 1–375

What is the importance of dust and pollen in the air? 1–377

Things to Think About

How are the harmful rays of the sun kept from reaching us?

Why is carbon dioxide necessary to life?

How does the air help carry hay fever?

How does dust in the air affect our health?

Picture Hunt

What are the sources of dust in the atmosphere? 1–376

When do burning objects give out light? 1–373

Related Material

How is indoor air kept pure? 1–393, 409, 10–519

How does the air supply plants with food? 2–41, 43, 45

Why is air necessary for combustion? 1–4, 384-85

How does the air affect light? 1–424-26, 427, 431

How does sound travel through the air? 1–445-46

How are kites used to study the atmosphere? 14–500

How is the atmosphere related to the weather? 1–259-61

How may air pressure affect the ears? 2–304

Practical Applications

How is helium used in transportation? 1–375-77

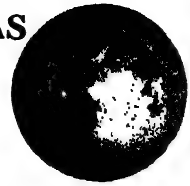
How are some of the rare gases of the air used in electric lamps? 1–376-77

How is carbon dioxide used in refrigeration? 1–375

Summary Statement

The ocean of air in which we live is composed of nitrogen, oxygen, carbon dioxide, water vapor, dust, and traces of certain rare gases.

The WONDERFUL GAS *in* WHICH WE LIVE



Living on a Vast Planet and Free to Roam Everywhere upon It, Man Is Nevertheless a Prisoner in the Air on Its Surface

WE LIVE our lives on the hard crust of a huge ball eight thousand miles thick; it is immersed in an ocean of air. Like the creatures which inhabit the ocean of water, we are forever confined to our surroundings, depending upon them for existence. But unlike marine animals, we do not swim about in our ocean; for ours is composed of gases, not liquid. The force of gravity keeps us at the bottom. Exerting all our bodily strength we can jump up a distance of perhaps five or six feet. Applying our minds and taking advantage of machines, outside energy, and artificial wings, we can soar to a height of five or six miles. Yet, it is so difficult to overcome gravity that we are indeed proud of being able thus to travel six miles farther away from the earth's center. We are prouder still of the achievement of the scientists who recently extended this distance to as much as ten miles, into what is called the stratosphere (strā'tō-sfēr). But what is ten miles when our nearest neighbor in space—the moon—is 240,000 miles away? Whether we shall always be kept prisoners at the bottom of an ocean of air depends upon our ability to understand the nature of this ocean. We must rely upon fearless pioneers who in one way or another explore its depths and its heights, at the risk of their comfort and their lives.

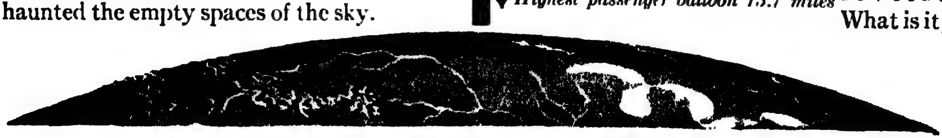
The air has always been a baffling mystery to mankind. Before the development of science had taught the world that there was a natural cause for every effect, many superstitions arose concerning the atmosphere. Primitive man associated it with invisible beings, gods and devils who haunted the empty spaces of the sky. When these terrible powers were angry, they sent down death and destruction. The swift rush of the wind seemed like the arrival of spirits, and the awesome moan of a gale sweeping through trees brought to mind the lost souls in distress. The fact that rain, snow, hail, lightning, and thunder came from the sky led men to believe that it was necessary to appease the wrath of the gods of the air.

To-day we have learned to discard these ideas, largely because of our ever-growing knowledge of the atmosphere. Yet the mystery is, in many respects, as great as ever, since much of the upper regions of the air are unexplored. Only a small beginning has been made. Sounding balloons carrying only self-recording instruments have gone up thirty miles. There is air farther up than that, however. How high up does the atmosphere go? Opinions differ. Some say 150 miles; others 200 or 250 miles. Sir James Jeans, the great English scientist, has calculated that traces of the atmoshpere extend to heights of 2,000 miles. What lies between these upper strata and the earth? Does the stratosphere end at 30 miles or so, to be succeeded by layers that are warm? Will airplanes be able to move through the stratosphere, at speeds of a thousand miles an hour? Do our earthly storms originate at these high levels? What is it,

We live at the bottom of an ocean—an ocean of air. We try hard to leave this ocean bottom, in order to explore the depths above, but the pull of gravity is too much for us. Captains A. W. Stevens and O. A. Anderson have gone higher than anyone else, but their best was only 13.7 miles. The air surely reaches up more than 200 miles. Some say that air can be detected as high as 1,000 miles.

End of atmosphere probably 1000 miles

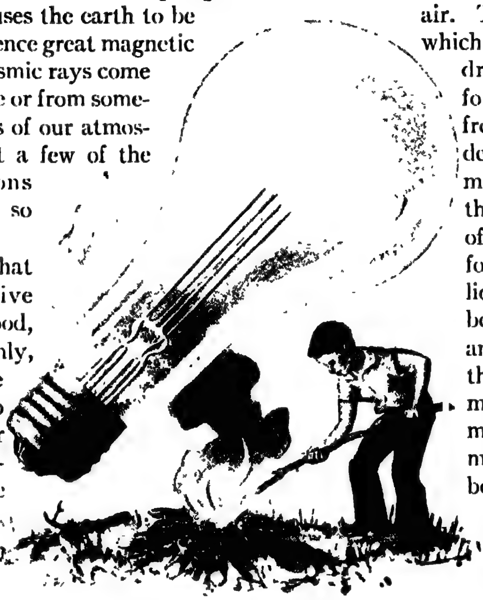
Highest passenger balloon 13.7 miles



high in the air, which reflects the radio waves, making it possible to send messages to every part of the globe? What is the nature of the layer of air which seems to filter out those of the sun's rays which, if they could come through, would kill every plant and every animal on earth? Is there something high up in the air which causes the earth to be a magnet and to experience great magnetic storms? And do the cosmic rays come to us from distant space or from somewhere in the top layers of our atmosphere? These are but a few of the unanswered questions which make air study so fascinating.

Someone has said that life depends upon five things: air, water, food, heat, and light. Certainly, air deserves first place in the list. We can do without food and water for days, we can withstand for a time the fiercest cold and darkest gloom; but without air the spark of life may be snuffed quite out in only two minutes.

Air is invisible to us, chiefly because we are immersed in it. In this respect we resemble fish who do not see the water. One of the requirements for distinguishing objects is that there be a well marked boundary line between the objects and their surroundings. At times, however, the air assumes many colors. The deep blues, and the reds and purples of sunset and sunrise, are all due to the dust particles of various sizes that are ever present in the atmosphere. But we have already told you all about the air elsewhere in these books.



When things are sufficiently hot, they glow, giving out light. Rapid burning almost always develops enough heat to cause a glow, or "incandescence," but in the case of a fire, oxygen is needed to support the combustion. Inside an electric lamp there is no oxygen, and there can therefore be no burning; yet the filament grows so hot that it gives out light. The light which comes to us from the sun is from heated substances which glow in somewhat the same way as does the filament in an electric lamp.

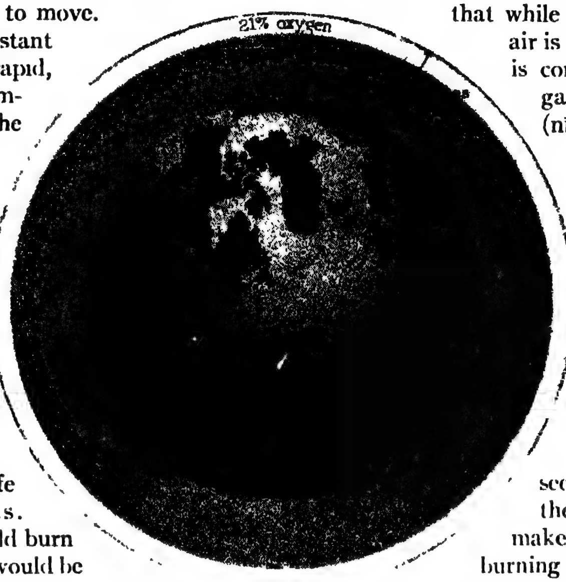
How Fast Is the Sun Losing Heat?

Many scientists believe that the sun is losing its heat at such a rate that fifteen trillion years from now it will have ceased to glow. If that be so, what is the final fate of our atmosphere? Air remains a gas because the surface of the earth and its interior are warm. Without this warmth the gases in the air would condense to liquids and fall as air-rain upon the earth. If cooled enough the liquid air would freeze to solid air. The entire atmosphere, which now reaches up hundreds of miles, would form a rocklike layer of frozen air thirty-five feet deep. This fiercely cold mantle would envelop the entire globe in a grip of death. Of course, before this could happen the liquid air would have been absorbed by the soil and the appearance of the earth might be very much like that of the moon to-day, or like many other heavenly bodies that seem devoid of an atmosphere. At any rate, the human race has many millions of years ahead of it, before this terrible future arrives.

In the writings of ancient China we find the notion that in air there are two things: one which makes things burn and another which does not. This rather sound idea seems to have been forgotten in the centuries that followed; for, as recently as the 18th century, air was believed to be an indivisible element. Not until 1771 was it discovered that air was a mixture of gases. The first of these to be identified was oxygen. Scheele, the Swedish scientist, was among the early experimenters who studied oxygen; and Lavoisier (lȧ′vwȧ′zyā′), a Frenchman, proved that about one-fifth of every cubic foot of air was oxygen. Lavoisier also proved that oxygen makes things burn. We have learned since that most objects are slowly burning because of this element

in the air. In a sense, life itself is a process of slow burning; for the oxygen we take into our lungs reaches the blood stream which is pumped by the heart to every cell of the body. There it enables particles of digested food to burn slowly, so that we may have heat and so that our muscles may have energy with which to move.

Because of constant burning, slow and rapid, oxygen is found combined in many of the earth's substances. Only a few billion tons of the gas are free in the air. It would make an astonishing difference in our lives if, instead of one-fifth, the air contained three-fifths or four-fifths of this life supporting gas. Wood and coal would burn so furiously that it would be dangerous to light them. The heat generated might melt and even burn the stoves themselves. A building on fire would be like a raging volcano, from which the steel would flow in molten streams. A person lighting a cigarette would find his face enveloped in flames.



There are several different gases in the shell of atmosphere which surrounds our earth. Most of it – 78 per cent – is nitrogen. Nearly all the rest of it is oxygen, without which we could not live. One per cent of the total consists of carbon dioxide, water vapor, and other gases. Of course all the gases shown in layers in the diagram are really mixed together in the air.

Nevertheless we use tanks of pure oxygen in many ways. Hospitals find it useful in keeping alive patients that are gasping for breath; under water, in caissons and in submarines, pure oxygen is used to replenish the air supply; mountain climbers and aviators depend upon it when they reach very high altitudes; and often we make use of pure oxygen to produce a flame hot enough to cut steel under water.

So oxygen is used constantly by man, by animals, by plants, and by fires of every description. The processes of decay and of rusting also require oxygen. So far as man can learn, there is only one form of minute bacteria which seems to live in an oxygenless world. Why, then, is not the supply of oxygen exhausted? Because plants produce and give off more of this gas than they use. The vegetable kingdom puts oxygen into circulation again.

Accurate measurement by scientists shows that while 21 per cent of the air is oxygen, 78 per cent is composed of another gas called nitrogen (nī'trō-jĕn). Thus we account for 99 per cent of our atmosphere. Nitrogen is an interesting gas. We breathe it in and we breathe it out, without making the slightest use of it in our bodies. Its chief purpose seems to be to dilute the oxygen and so make less violent the burning process that goes on all about us.

The chemist speaks of nitrogen as an unfriendly element because it is so difficult to make it combine with other elements. On occasion, however, nitrogen does make combinations, producing such interesting substances as dynamite, perfumes, dyes, fertilizers, and medicines of various kinds. The power plant at Muscle Shoals, to which we have referred, was built for the special purpose of forcing nitrogen and oxygen to combine by means of electric energy. A bolt of lightning often causes the nitrogen and oxygen to unite chemically. The rain carries the combination to the soil, where plants may feed upon it. Later, when plants, or the animals that eat plants, decay, the nitrogen returns once more to the air.

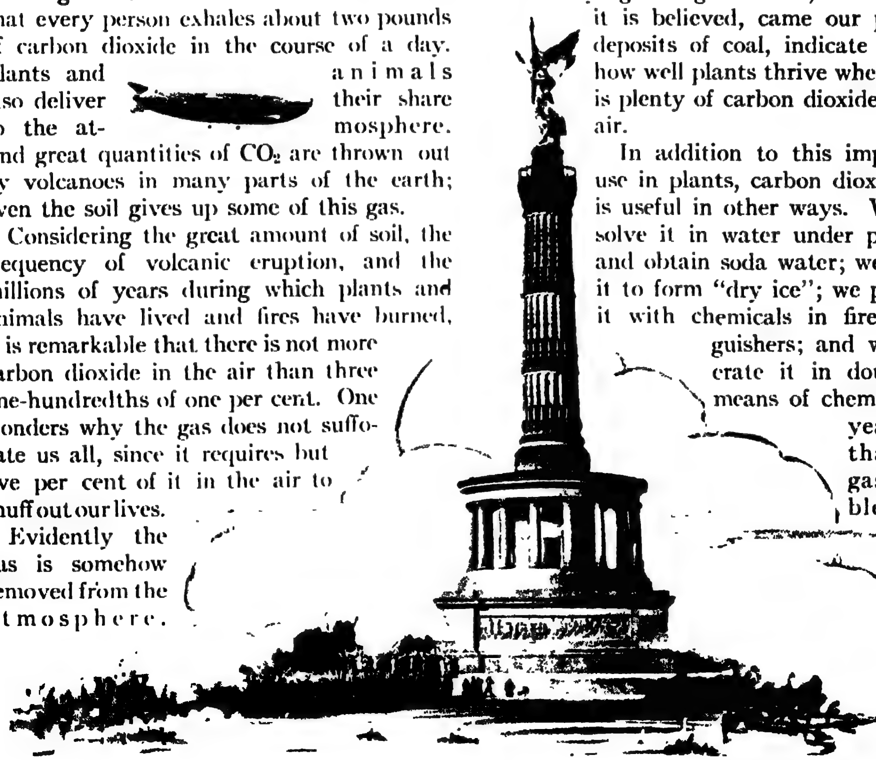
But what does the remaining one per cent of the air contain? In answering this question we shall first describe two extremely essential gases, and then give a list of several

others that are interesting but not very important parts of the air. But essential or not, let us bear in mind that all of these gases together make up only one per cent of the atmosphere which surrounds the earth.

Two Gases Essential to Life

The first of the two essential gases referred to is carbon dioxide (dī-ŏk'sīd). Ordinarily, three one-hundredths of one per cent of the air is carbon dioxide— not very much, perhaps, but so vital that without it life such as ours would cease. Let us see why this is so.

A molecule of this gas contains one atom of carbon and two of oxygen; so the chemist refers to it as CO_2. When wood and coal burn, one of the chief products of the burning is carbon dioxide, which passes into the air. Similarly, when food is slowly burned in the bodies of plants and animals, this gas is discharged. It has been estimated that every person exhales about two pounds of carbon dioxide in the course of a day. Plants and animals also deliver their share to the atmosphere. And great quantities of CO_2 are thrown out by volcanoes in many parts of the earth; even the soil gives up some of this gas.



The chief use to which helium gas is put is the floating of the airships that sail so majestically above the tops of the tallest structures.

Considering the great amount of soil, the frequency of volcanic eruption, and the millions of years during which plants and animals have lived and fires have burned, it is remarkable that there is not more carbon dioxide in the air than three one-hundredths of one per cent. One wonders why the gas does not suffocate us all, since it requires but five per cent of it in the air to snuff out our lives.

Evidently the gas is somehow removed from the atmosphere. Rain has this effect when it falls through the air. Certain kinds of rock, too, help to absorb it. Much of this absorbed and dissolved carbon dioxide reaches the ocean by way of rivers and streams. Millions of sea animals feed upon it, changing what was once carbon dioxide into shells and coral islands. The greatest amount of atmospheric CO_2 is absorbed by the leaves of plants. Leaves must have this gas in order to manufacture food for the growing plant. Incidentally, the plant releases oxygen to the air in the process of feeding upon carbon dioxide.

And so the balance is restored; that is, neither oxygen nor the carbon dioxide in the air change very greatly in amount. But this has not always been so. There is some evidence that many millions of years ago, the proportion of carbon dioxide was much greater. In such an atmosphere plants flourished tremendously. The vast marshy jungles of giant ferns, from which, it is believed, came our present deposits of coal, indicate clearly how well plants thrive when there is plenty of carbon dioxide in the air.

In addition to this important use in plants, carbon dioxide gas is useful in other ways. We dissolve it in water under pressure and obtain soda water; we freeze it to form "dry ice"; we produce it with chemicals in fire extinguishers; and we generate it in dough by means of chemicals or yeast, so that the gas bubbles will

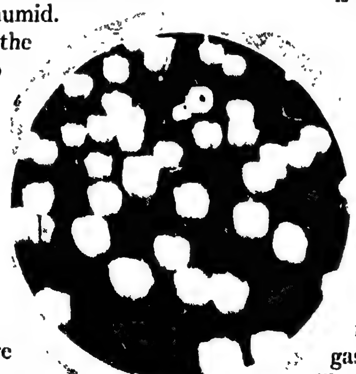
make bread and cake spongelike and consequently more digestible and more palatable.

The air is never free of dust, even on the clearest days and at high altitudes. Of course, the number of particles differs with the locality. Above, you see what large quantities of soot and other impurities a single factory can send forth. In some factory towns the dust has become an actual menace to health.

Active volcanoes send a great deal of dust into the air. In one eruption, some fifty years ago, the volcanic dust spread to all parts of the earth, causing red sunsets for months after the explosion.

One puff of tobacco smoke may throw as many as a billion dust particles into the air. Of course we should not assume that dust is always dangerous to health; but it is something to consider carefully and to control.

The second of the essential gases that constitute the remaining one per cent of the air is water vapor. The amount of it varies with the locality, with the season, and with the temperature. When air contains all the water vapor it can hold at any given temperature, it is said to be saturated and one hundred per cent humid. If it contains none at all, the humidity is said to be zero per cent. No place on earth ever has zero humidity; but ninety per cent and even one hundred per cent humidities are frequent in many parts of the earth. The part that this vapor plays in the world has been described on other pages where we tell about the weather.



At certain seasons of the year the air is loaded with pollen from the flowers of various plants. Without it flowers cannot develop their seeds.

The chief sources of atmospheric moisture are plants and animals which discharge it from their bodies; the lakes and oceans, which give off a great deal of water vapor under the rays of the sun; and the process of burning, which usually results in the chemical combination of hydrogen and oxygen.

In answer to the question, "What does the air contain?" we have now described four different gases: oxygen, present to the extent of 21 per cent; nitrogen, 78 per cent; carbon dioxide, .03 per cent; and water vapor, present in widely varying quantities. But that is not all. There are five additional gases to be found in the air in small quantities. They are in the air chiefly because they do not combine chemically with any other element on the earth. They exist alone and always have done so, in so far as scientists can observe. As in the case of nitrogen, we inhale these gases with every breath and exhale them again. Our bodies can make no use of them. Because they are so "exclusive," scientists often refer to them as the "noble" gases. Perhaps the reader would like to learn their names. In the order of amount present in the air, they are: argon, neon (nē'ŏn), helium (hē'li-ŭm), krypton (crĭp'tŏn), and xenon (zē'nŏn). The lightest of these gases is helium and the heaviest is xenon.

It is of interest to note that three of these

gases have become very useful. Helium, because it is light and because it does not burn, is used to inflate the bags of balloons and dirigibles. It is not quite so light as hydrogen but much safer to use. Neon and argon are employed in the relatively new kind of electric lamp so popular for store displays and advertising signs. A small amount of neon introduced into the long and variously shaped glass tubes of an advertising fixture gives a penetrating orange-red color when electricity is discharged through the tube. Argon, used similarly, results in a greenish-blue light.

In order to complete our list of air constituents, we might mention the fact that many scientists have discovered traces in the air of the gases hydrogen, ozone, and ammonia.

The Evils and Uses of Dust

A beam of sunshine passing through a window into the air of a room brings to view a myriad of dancing particles. Air is never quite clear. At the tops of mountains, as on the desert, dust is always present. Each puff of tobacco smoke sends millions of tiny specks of matter into the atmosphere. The wind lifts particles from plants, from animals, and from rocks, and scatters them far and wide. A volcano in eruption belches forth huge volumes of fine dust and ash that circles the globe by way of the air. Chimneys add their share to this solid part of the atmosphere, as do the plants when their pollen is carried out upon the breeze. Even the meteors, in burning, finally settle as dust in the air. Unfortunately, some of the air-blown solid matter provides a shelter and a feeding ground for bacteria; many of which are harmful to health. The number of these germs, however, is believed not to be alarming, as a rule.

In large cities the dust evil is, of course, about at its worst. Lungs, furniture, and clothing suffer considerably. Also, workers in chemical factories and in other establishments where special substances are used, meet unusual dangers to health in the air which they must breathe. In general, however, there is little to fear from atmospheric dust or from disease transmitted by way of the air. During the long years which man has spent under such conditions, he has evolved many bodily defenses and many adaptations which serve him in overcoming the solid particles which enter his breathing mechanism.

It may perhaps surprise our readers to learn that dust has its uses and, in one respect, is rather essential. Beautiful sunsets or sky colors of any description would be quite impossible were it not for the fact that dust acts as a color filter and reflector. The most beautiful effects are produced when the sun's rays pass through air that is heavily laden with dust particles. The colors that result depend upon the size of the particles and the direction of the sun's rays as they enter the eye. But the most important rôle which dust plays in life is to act as centers around which atmospheric moisture may gather, and then fall as rain. Rainfall would hardly be so frequent or so plentiful if there were no dust in the air.

As a summary of the facts set forth thus far, let us imagine that in some mysterious way one could separate the air into its parts, and that these parts could be carefully laid one upon the other, the heaviest at the bottom and the lightest at the top. We should then have resting upon the surface of the earth:

A five-inch layer of liquid water
A 50,000th of an inch of xenon
A half-inch layer of krypton
A very thin film of ozone
A thirteen-foot layer of carbon dioxide
A ninety-yard layer of argon
A five-inch layer of neon
A one-mile layer of oxygen
A four-mile layer of nitrogen
A half-inch layer of helium
A thin film of hydrogen
A sprinkling of dust

PHYSICS

Reading Unit
No. 13

THE DANCE OF THE MOLECULES

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What are the conditions inside a solid iron bar? 1-380
How fast do molecules move? 1-380
Can iron evaporate? 1-381
Heat, the energy of molecules, 1-382
Heat from electricity, 1-383
Tapping the earth's heat, 1-383-84
Burning without light, 1-384
Why water puts out a fire, 1-385

Things to Think About

What is the source of most of our available energy?
How does a knowledge of the conditions necessary for fire teach us how to put out fire?
How may fires start by themselves?
How can we explain the different effects of heat upon substances?

Picture Hunt

What is the liquid in this cascade, what makes it so hot and bright, and what change is gradually going to take place in it as it cools off? 1-379
Why do objects expand when heated? 1-381
How does friction produce heat? 1-382
How may volcanoes be put to work? 1-383

Related Material

How may molecules be arranged in some substances? 1-361
What is the size of a molecule? 1-280
How may the heat produced by friction be reduced in machines? 1-319, 321
How does friction help and hinder man? 1-319-21
How are homes protected against fires caused by too much electric current? 1-384
How may bacteria cause fires? 2-19
What is the origin of fire, according to Greek mythology? 14-421

Practical Applications

How is molecular friction used to start fires? 1-382
How are fires put out? 1-385

Leisure-time Activities

PROJECT NO. 1: Make a flint-and-steel outfit for starting fires, 1-382, 10-332.

PROJECT NO. 2: Make a primitive fire drill for kindling fires, 10-333.

In a cascade of terrible heat and brilliance this copper from the famous Flin Flon mine in Canada is being poured into the giant ladles at the bottom of the picture. It is hard to believe that this is the same red metal that we see in our pennies. Yet that is true. It is in no way changed except that the molecules which make it up have been made to move about with terrific speed. In other words, the copper is hot—so hot that it has been turned into a liquid and gives off a brilliant light. As the molecules slow down in their wild race the copper will gradually cool and harden. For that slowing down is the same thing as cooling off.

Canadian National Film Board Photo

The DANCE *of the* MOLECULES

Objects Are Warmer When Their Molecules Dance Faster; but No Object Is Ever So Cold that the Dance Stops Altogether

MOST of us like to explore places where no one has ever been before. That is why Commander Byrd and others suffered hardship at the Poles. That is why Beebe descended deep into the sea, and Piccard rose high into the atmosphere. For the same reason scientists are experimenting with rockets, hoping that some day men may be able to shoot themselves far into space, there to explore at close range the mysteries of the heavens. But there is one kind of world where man himself can never hope to go, because he is much too large. This is the world of atoms and molecules (mŏl'ē-kūl).

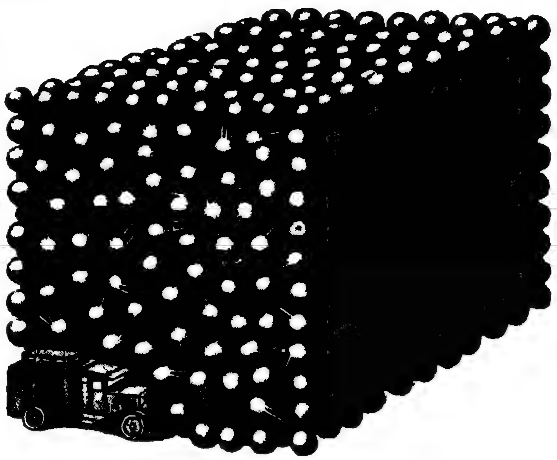
Of course most explorers have a serious purpose when they start on their travels. They seek wealth or fame or new knowledge, as well as enjoyment. Nevertheless they are fascinated by the unknown, and are thrilled as much by danger as by discovery. No greater mystery exists than the world of the infinitely small; and yet, if we are ever to explore its regions, we shall have to do so by indirect means. Now indirect means are valuable and important. Already they have led us to many discoveries and much knowledge. Though it would be more interesting to make an actual journey among the molecules, we may, with the knowledge already possessed, plan an imaginery trip.

To begin with, it is necessary that we shrink to a size so small that we can move freely through the spaces between molecules. Perhaps one does not realize that such spaces exist in an object as solid as a bar of iron; but they do. In order to enter, we become at least as tiny as the molecules themselves.

It is useless to say how small that is; but we may get some notion of the size by realizing that if the earth itself were to shrink in the same proportion, the globe on which we live would be no larger than a tennis ball.

Having succeeded with the process of shrinking, let us embark on a trip of exploration through a solid bar of iron. In imagination we provide ourselves with some sort of car which can move as we wish it to, and which can protect us from all harm. We are provided with a searchlight to see our way.

The first strange sight that greets us is the disappearance of the shiny smooth surface of the bar. Instead, we see that the boundary line between air and iron is full of irregularities. And besides, the high spots and the low spots in the surface of the iron are not fixed; they change constantly. This, of course, is no great wonder for us. We are quite familiar with the fact that a well-kept lawn seems as smooth as silk to an observer in an airplane; but to an insect crawling among the blades of grass, the field appears as rough as a forest of giant trees.



There is a fascinating trip that man can never hope to take, because he is much too large. Nevertheless one can take it in imagination. Here in the picture is the armored car which is going to be our conveyance. It has already shrunk sufficiently so that its passengers can see the molecules in a piece of iron in their somewhat orderly arrangement. But of course the molecules are not at rest, as they might seem to be here. They swing to and fro with great speed.

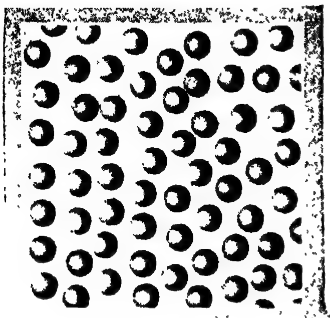
The Great Speed of the Molecules

A second remarkable sight which greets our eyes is the movement among the iron molecules. There are trillions of them, but not a single one is quiet. They fly hither and thither at great speed, colliding with one another and rebounding with the impact. It is hard to realize that this dancing mass of molecules is actually a bar of iron that rests motionless when the normal human eye looks at it. Again, this experience reminds us of an airplane view of a distant forest. The trees look fixed and motionless when we are high above them; yet we know that the branches are tossing in the breeze.

We guide our car carefully, so as not to run into a molecule. Not that we fear the danger of collision! But we do not wish to interfere with the movement we came to study. Traveling about in this seething and excited world, we notice that groups of iron molecules tend to arrange themselves in certain regular ways. It is difficult to see just what form the group of molecules takes; but the regularity of the form is as geometrical in outline as is a cube. There seems to be layer upon layer of these nicely arranged groups of molecules, in spite of the fact that each molecule is dancing to and fro.

Now we signal to our friends in the giant human world to place the bar of iron on a hot stove. When this is done, a new excitement begins all about us. The stove molecules seem to be moving back and forth furiously; and when they strike the bar molecules, the latter too rebound with greater speed. In a little while we find ourselves moving through a world of molecules that are moving much faster. We receive word from our friends that the bar of iron is now "red-hot"; but all we see is that the molecules move faster. We signal back to ask that the stove be made hotter. After an interval, we receive the reply that the iron is "white-hot" and that it will soon melt. We look about us for some change in the molecules; but aside from greatly increased motion we see very little alteration. When word comes that the bar is melting and that it has had to be placed in a clay vessel,

we notice that the geometric arrangement of molecules is fast disappearing. With the report that the solid iron has changed to liquid iron, we find that all arrangement is gone, owing to the terrific motion. Can it be that the heat energy in a

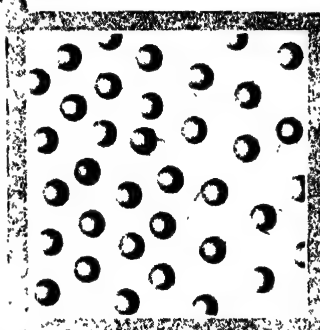


When an object is cold, its molecules do not dance so fast as when the object is warm. Hence they can stay closer together.

body is nothing more than the movement energy of its molecules?

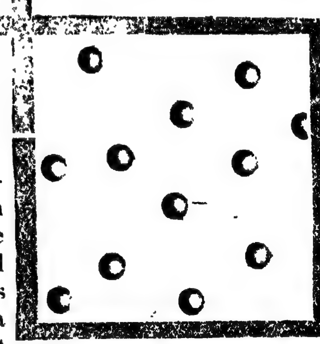
Certain it is that we ourselves feel nothing of the stove's heat. The only effect upon us is that we need to be more watchful in steering the car, since it is now more difficult to dodge the speeding molecules. How much faster can they go? That is the question which now comes to mind. And to get an answer we send word to our friends that more heat be added to the pot of molten iron. At the surface of the hot liquid we notice a strange effect. Now and again an iron molecule is hit so hard from below that it flies up and away from the pot. The air above the surface contains numerous molecules that have been kicked off in this way. We are reminded of the particles of water which evaporate from the surface of the water in a glass. Evidently liquid iron, too, can evaporate. Occasionally we see molecules of iron return to the molten liquid; but as many others go shooting into the air to take the places of those that have left it.

Adding more heat to the pot has the effect of adding more speed to the molecules. Now they not only move faster, but they cover more distance. Evaporation increases in amount. Soon the excitement is so great that thousands of iron molecules together are discharged into the air. At this point we receive a message that the molten iron is boiling away into iron steam which glows with a light that dazzles the eyes of human observers. In our tiny car, we see nothing of all this. So far as we are concerned, the addition of heat has had but two noticeable effects. One is the continued increase in speed of the iron molecules; and the other is the ever widening distance between molecules. We notice that our car must travel over a vast amount of space when the bar of iron has changed entirely into iron steam. The iron molecules are scattered freely among molecules of air.



When heat is added to an object, the motion of the molecules in it increases in speed. They therefore collide harder and bounce back farther, and the spaces between them grow wider.

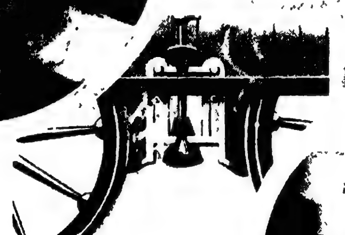
Since the addition of more heat brings no new changes in the iron steam, we decide to let the iron grow cold. The signal is given and we watch for results. Slowly but steadily the molecular dance becomes less violent. In time, the speed slows down to a point where our friends tell us that the steam has condensed to molten iron again. Later we receive word that the liquid is becoming solid; and finally the solid iron is as it was in the beginning, except that its shape is that of the containing pot rather than that of a bar. Throughout the cooling process, we notice only the slowing down of the speed of the molecules and the contraction of the space they occupy.



When an object is made very hot, the speed of the molecular dance is furious. Collisions increase, the spaces between the molecules grow much wider. The object as a whole expands.

The continued slowing down of the moving molecules makes us curious to see if they

can be stopped altogether. In order to find out, we send this message to our friends in the giant human world: "Can you make the iron very cold?" "How cold?" is the reply. "As cold as ice," we say, waiting to see what happens. The results are somewhat disappointing; for packing the metal in cracked ice causes only a slight decrease in molecular speed. "Can you make the iron still colder?" we flash to our friends. After some delay we learn that the pot containing the metal has been placed in a refrigerator; but the molecules still dance, in spite of the fact that the degree of coldness of the iron is now 20 degrees below that of freezing water. Our constant requests for less and less heat result in the use of dry ice and then of liquid air, which is about 300 degrees colder than freezing water. This has an appreciable effect upon the dancing molecules, but it does not stop them. Finally, liquid hydrogen and then liquid helium are poured over the pot of iron. In our car we are as unaware of the fierce cold as we were of the fierce heat. We notice only the marked slowing down of the molecules. Liquid helium makes them move very sluggishly indeed; but they do not stop. Try as our friends will, they can never get the iron so cold that the molecules cease moving altogether.



Here are four instances in which the molecules of a body are being made to dance faster. When we rub our hands together, we feel the mechanical energy changing into heat energy; that is, we can feel the increased speed of the moving molecules of the skin and flesh. In the upper circle the molecules in a steel bar are being made to move with greater speed as the bar is heated by rubbing a rough surface against it. The brake shoe resting against a turning trolley wheel may smoke from the heat produced as it rubs against the wheel. Finally, striking a spark with flint and steel shows how a blow may heat an object until it glows.

Our exploration at an end, we decide to return to our own world. The knowledge we sought has been found. We now know that molecules do not get hot and they do not get cold. There is no such thing as a warm molecule or a cold one. Yet when heat is added to a body, its molecules dance faster and usually move further apart. When heat is taken away, the molecules move more slowly. Heat energy, then, is the mechanical energy of molecules. On earth, no object is ever so cold that its molecules stop their perpetual dance.

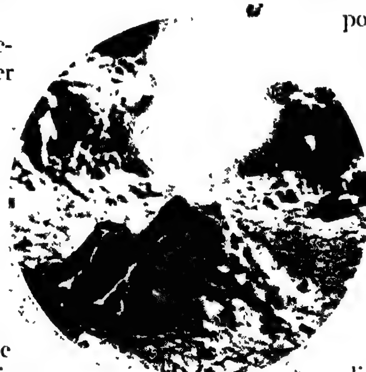
If your hands grow numb with cold, you probably rub them until they are warm again. As your hands grow warmer, their molecules move faster. One way of describing what happens is to say that friction produces heat. Another way of stating this is to say that the mechanical energy used in overcoming the force of friction is changed into heat energy. Thus, instead of the motion of one hand across the other, we have an increase in the motion of their molecules.

We have all noticed that friction produces heat in the manner just explained. Sliding down a rope or a bannister burns the hands. A drill boring into wood or rock becomes extremely warm. A machine that is not regularly oiled to reduce friction burns out its bearings. Running an automobile with the emergency brake "on" often sets fire to the car. In many

The earth itself is a source of heat energy. It is believed that, except for its outer crust, our globe is a fiercely hot ball of iron. Perhaps this explains the steaming hot waters of the New Zealand lake shown above. Other hot springs are found in Yellowstone Park and in frigid Iceland.

other ways we are made aware of the fact that one of the simplest ways of getting molecules to move faster is to rub the object in which they lie. Friction is a source of heat.

Of course we do not depend upon friction altogether when we wish heat. Before savage man learned to make fire by rubbing a stick on wood, he probably knew that a vast amount of heat exists in the earth itself. He saw huge tongues of flame belch forth from volcanoes, and occasionally he found springs of hot water issuing from the earth's interior. To-day we believe that the earth is really a fiercely hot ball covered with a cool but very thin crust. As we go down in a mine the air gets noticeably warmer. In fact, one reason why mines cannot be dug deeper than two or three miles is that the high temperature makes work impossible. Some day, perhaps, we shall learn how to resist this heat; and then we shall tap the reservoir of heat energy which exists under our very feet. It has been suggested that when all other sources of heat are exhausted, we can simply use the heat in the interior of the earth. Indeed, a famous English scientist has proposed a plan by which a well twelve miles deep may be dug in order to draw upon the heat of the earth. And in some parts of the world steam issuing from cracks in the rock is stored in tanks and used to run steam engines.



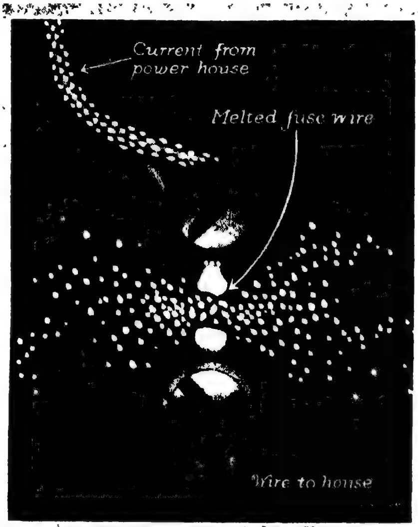
Volcanoes are one of the evidences of the heat which exists in the earth's interior. Some day we may find a method for putting such energy to good use.

Perhaps the most convenient source of heat to-day is a current of electricity. Just as a bolt of lightning may set fire to a house or a tree, so, on a much smaller scale, the flow of electricity through a wire makes the wire hot. The amount of heat thus obtained depends upon the kind of wire used and the amount of current which flows. The ordinary electric iron is a good example of heat obtained through the flow of electricity. So is the electric radiator, the toaster, and the coffee percolator. Everyone is familiar with the heat given off by a lighted electric lamp. Also

we depend upon heat produced in this way to "blow the fuse"; for too much current melts the fuse wire, thus protecting the house against fire.

But electric heat is expensive as well as convenient. Besides, in order to generate electricity, heat must be obtained in some other way; for dynamos are usually driven by steam engines and these engines must have steam that comes from boiling water. The cheapest and the easiest way of getting large amounts of heat energy is to make a fire. Fire has always been and still is our most important source of heat.

Just what is fire? Some people would say it is the "flame"; others would call it the "smoke"; still others might say the fire was the burning substance itself. The best way of describing fire is to say that it is the light and heat which comes from the process of burning. Now, burning may be slow or rapid. When it is slow, very little, if any, light is given off. When it is rapid, light as well as heat is released; though there is always more heat than light. But whether burning is fast or slow, the scientist calls it a process of "combustion." Combustion (kŏm-bŭs′chŭn) is a source of heat.



Perhaps the most convenient source of heat is the electric current. Frequently it is too expensive to use on a large scale; but every house that has electric lights uses the heat from electricity as a protection against fire. Above, you may see what happens when too great a flow of current "blows the fuse."

When Burning Objects Give No Light

Many things will burn, if conditions are right, and in burning, liberate heat. Long ago man learned how to get heat from the combustion of wood, grass, and leaves. Now we also use coal, gas, and oil. All around us, however, substances are slowly burning, yielding heat but no light. Iron that is rusting is really iron that is burning slowly. Food, when eaten, burns slowly in the body, providing us with much heat. In fact, so much heat is developed by the human body that, as a rule, it works hard to get rid of much of this heat. Occasionally we hear of dangerous fires which are started by a slowly-burning object. An innocent-looking oil rag is thrown into a corner and forgotten. The oil begins to burn slowly. Some heat is generated, but no light. Hence no one sees the "fire" in the rag. Since the rag is usually crumpled up, the heat is largely retained in the folds, where it accumulates. Eventually the rag bursts into flame, causing much damage. Fires of this kind are referred to as being caused by "spontaneous (spŏn-tā′nē-ŭs) combustion."

To make a fire there must first be a fuel of some kind; that is, there must be a substance that will burn. One cannot build a fire with stones or sand or iron. These substances are not fuels. Coal and wood, gasoline and alcohol, hydrogen and acetylene gas are among the fuels most commonly used. Of the six fuels mentioned, two are solid, two are liquid, and two are gaseous. Of course, there are many others of each kind.

Secondly, no fuel can burn unless there is air to support the combustion. A constant stream of air must pass up through the stove grate. A clogged chimney results in a poor fire and may even put the fire out. Fanning a glowing ember causes it to burst into flame. Every automobile engine has a carburetor which mixes air with the gasoline. Every gas stove has an air vent through which a proper amount of air must enter in order that a hot flame may be obtained. And every human being must breathe—for no other reason than that air is necessary if food is to be burned.

Thirdly, a fuel must be raised to its

kindling point before it will burn. No matter how burnable an object may be, or how much air may be present, a fire does not start before that point. It must first be "lighted," "set afire," "kindled." Even in the case of spontaneous combustion the oil and the rag did not burn until the gradual heat accumulation raised the mass to the kindling point. Of course different substances kindle more or less easily. A piece of phosphorus is kindled by the warmth of the human hand; a piece of paper requires the heat of a lighted match; even iron bursts into a sparkling flame if raised to a high enough temperature in an atmosphere of oxygen.

When you put out a candle's flame by blowing on it sharply, you are interfering with at least one of the three essentials for burning. You are removing the burnable mixture of vaporized tallow and air.

Knowing the three essentials for making a fire teaches us how to put fires out or to prevent them. Fireproofing is based upon the first essential for making a fire; namely, one must have a burnable substance. Clearly, if a house or a garment is coated with a layer of some substance that does not burn easily, the house or the garment is thereby protected against fire. Wetting an object makes it fireproof for some time, since the film of water which surrounds the object is an unburnable substance. When a trench is dug in the path of a prairie fire or around a burning forest, the idea is to remove all further fuel and thus confine the fire to a limited area. Asbestos is the most popular fireproofing material, because it does not burn.

A second method of extinguishing fire is based upon the second essential requirement for a fire; namely, the need for air or oxygen. Once a huge oil well took fire and spouted flames several hundred feet into the air. The fire was finally put out by lowering over the blaze a large steel dome. When the air in the dome was used up, the fire died down. At another time a similar oil-well fire was extinguished by discharging a blast of dynamite near the flame. The force of the explosion blew the air away, leaving a vacuum for a short interval of time. The fire was literally snuffed out. In fact, that is exactly what happens when one blows out a candle flame.

A very common method for putting out small fires is to surround the burning object with a heavy and unburnable gas. The gas pushes the air away from the object and the fire goes out. The gas often used in this way is carbon dioxide. It is generated chemically by inverting a tank extinguisher that is attached to the wall. Another gas used in the same way is known as carbon tetrachloride (tĕt′rȧ-klō′rīd), or more commonly, "carbona" and "pyrene." Carbona is a liquid which boils very easily, producing a heavy, unburnable gas. When sprayed upon a burning object, the liquid evaporates, and the resulting gas surrounds the fuel and displaces the air. Then the fire is extinguished.

Why Water Puts Out a Fire

Water is an excellent fire extinguisher for the reason that it does away with each of the three conditions essential for making a fire. In the first place, water is an unburnable substance. Secondly, it wets the fuel, thus preventing contact between fuel and air. Finally, it has a cooling effect upon the burning substance. This tends to bring down the temperature below the kindling point.

Thus far, we have enumerated four sources of heat: friction, the interior of the earth,

electricity, and combustion. Yet, in a sense, all of these sources are derived from a fifth—the sun. Friction, as we have learned, involves a moving body, and most of the motion of this kind on our earth is caused either by animals, by wind, or by water. Animals get their energy from the sun by eating the food which grows in sunlight. The wind is chiefly due to unequal heating of the earth's surface by the sun. Flowing rivers are constantly replenished by the rain of sun-evaporated water.

As for the heat inside the earth, we must bear in mind that the entire earth was once part of the sun. Electricity, too, is derived from the sun, for electricity is generated by a machine that requires heat; and this heat is usually obtained by combustion of fuels. Fuels, of course, are the direct result of sunshine. In the case of wood, it is recent sunshine; while in the case of coal and oil, the fuel is the remains of very ancient sunshine. Gaseous fuels are usually derived from wood, coal, or oil.

Thus we must always look to the sun for heat. If life is to go on, the sun must keep shining. Molecules will cease their perpetual dance unless that great heavenly body at the center of the solar system continues to pour forth its energy.

Why is the sun hot? Century after century it has managed to glow without any seeming reduction in its light and heat. Many of the greatest minds of science have been baffled by this puzzle. At first the answer given was that the sun is hot because it is burning; but this soon appeared to be ridiculous. If the sun were made entirely of coal and oxygen, it could not possibly burn for longer than fifteen hundred years or so.

The German scientist von Helmholtz (fôn hĕlm'hōlts) then proposed the idea that the sun is hot because it is contracting; that is, it is getting hot by squeezing itself into a smaller space. In this way the age of the sun was indicated to be about fifty millions of years, and its possible future only ten million more. But geologists at once protested, since there is evidence that the earth itself is more than two billion years old.

Then the explanation was offered that meteors pounding down upon the sun in great numbers keep the sun hot. But it was shown that to maintain the heat of the sun, there would need to be so many meteors that the sun's weight would double in thirty million years.

To-day most men of science believe, with Einstein (īn'stīn), Jeans, and Eddington, that the sun sends out heat by changing its matter into radiation. Each year the sun loses 120 trillion tons of its mass. Only a little bit of this comes to us upon the earth; but what we get we treasure as life itself, for in a sense this heat energy is life.

How Long Will the Sun Last?

How long will the sun last if it loses 120 trillion tons every year? Eddington, after many complicated calculations, tells us that it has still about 15 trillion years to go. If this be true, none of us need worry as yet. But what of the dim and distant future? Of course, we do not know; perhaps we cannot know; but the following is one picture of the future which is painted for us by a scientist, writing in "The New York Times":

"The sun cannot radiate forever. Like other stars, it must die—become a blackened cinder wandering through space. It will repeat the earth's career, except that it will have no other body to flood it with light and heat. It will acquire a thin, solid crust. Century after century gases will burst through. Streams of lava will pour out. The crust will become thicker and thicker—so thick that imprisoned lava will freeze into solid rock and metal. Water will be formed. Oceans will bathe the crust. The sun will be much like the earth—but a colossal dark earth on which only stars will shine. Ice will form, and at last the atmosphere will condense into seas of liquid gas. A slow shrinkage of the surface due to loss of heat will reduce the sun to a wrinkled mummy."

PHYSICS

Reading Unit No. 14

HOW FAST DO MOLECULES MOVE?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Heat and the speed of molecules, 1-389

Expansion and molecular speed, 1-389

The first thermometer, 1-390

Men who made early thermometers, 1-389-90

Metallic thermometers, 1-391

The doctor's thermometer, 1-392

Humidity, 1-392-93

Measuring minimum and maximum temperatures, 1-392

Things to Think About

How do different thermometers work?

Why is hydrogen used in a scientist's thermometer?

How does a doctor's thermometer h ld its reading?

Why does a partly deflated balloon expand to full size in the presence of a bright lamp or sunlight?

Picture Hunt

What are the known extremes of temperature? 1-392

How is a continuous temperature record kept? 1-393

Related Material

How is indoor temperature automatically controlled? 1-476-78

How does temperature affect plants? 2-104, 217, 4-133

How does temperature affect winds? 1-227

How is mercury used in a thermometer? 1-482

What is a treatment for heat exhaustion? 2-404

How high is the temperature of the electric arc? 1-513

What are the temperatures on the moon? 1-140

How does temperature affect health? 1-241, 392-93

Practical Applications

How are thermometers made? 1-389-92

How is the amount of water in the air determined? 1-393

Leisure-time Activities

PROJECT NO. 1: Make an air thermometer, 1-390.

PROJECT NO. 2: See how sensitive your hands are to differences of temperature, 1-388.

Summary Statement

The temperature of a body is an indication of the speed with which its molecules are moving. The fact that a solid, liquid, or gas expands when heated makes it possible for us to have different kinds of thermometers.

Photo by H. Armstrong Robert

Here is an experiment you will find amusing. Place your right hand in a dish of hot water and your left hand in a dish of cold water. After a few minutes place both hands in a dish of lukewarm water. It will surprise you to find that the tepid water feels hot to the left hand and cold to the right hand.

HOW FAST DO MOLECULES MOVE?

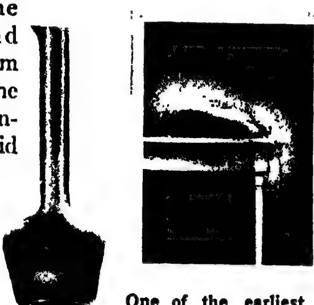
And What Happens to an Object When the Molecules in It Fall to Dancing Very Rapidly?

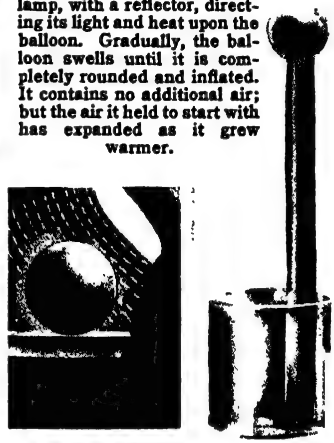
THE molecules of which all things are made are never at rest. We look at a massive boulder and say to ourselves, "This stone is motionless. Year after year it is found in exactly the same spot. Neither wind nor water nor weather can budge it." We may approach closer and examine with the minutest care any part of it. There is nothing to suggest motion. It is all fixed and stationary. But one must use his "mind's eye" in order to see anything so small as a molecule (mŏl'ē-kūl). And, using such eyes, we see the motionless boulder turn into trillions of molecules that quiver and dance to and fro. On a warm sunny day this dance becomes faster and more energetic; in the cold of winter, the dance slows down, but never stops.

Now, although we cannot see this dance except with our mind's eye—which is the same as saying that we must imagine it—we can and do feel the dance. Try placing your hand on a warm radiator and feel how the dancing molecules of the warm metal make the molecules of your hand dance. If the dance is too violent—that is, if the radiator is too hot—you quickly draw your hand away. In less time than it takes to tell about it, certain nerves in your hand transmit a message to your brain and spinal cord. This sends out an impulse which pulls your hand away and in your brain you have the thought that the radiator is too hot. Of course, it may not occur to you that "too hot" means "too violent a dance among the molecules." But if you are a scientist you will find it very convenient to think of it in that way.

Try the following experiment. Take three empty basins, each large enough to hold both your hands. Then fill the first basin with very cold water, and the second one with water as hot as you can stand; for you are

going to immerse your hand in this water. In the third basin mix hot and cold water in about equal amounts. Now, place your left hand in the cold water and your right hand in the hot. Keep them there for a minute or two. When you have grown accustomed to the different temperatures, remove the hands and place them both in the basin containing the tepid water.





One of the earliest thermometers ever made is shown at the left of the upper picture. It was devised by Drebbel, a Hollander, more than 300 years ago. The expanding liquid in the flask was colored water. Another type of thermometer, used by Galileo early in the 17th century, is shown at the right in the lower picture. Here the expanding substance was the air in the round glass bulb.

In the picture at the left you see a rubber balloon partly filled with air. It is, of course, flat and flabby. The picture below shows a strong electric lamp, with a reflector, directing its light and heat upon the balloon. Gradually, the balloon swells until it is completely rounded and inflated. It contains no additional air; but the air it held to start with has expanded as it grew warmer.

At this point, if you have followed instructions, an interesting experience awaits you. To the left hand, which has been in cold water, the tepid water feels hot; and yet the same tepid water feels cold to your right hand. Of course a basin of water cannot be hot and cold at the same time. If the molecules are moving with a certain speed in one part of the liquid, they move with equal speed in all parts of the liquid. What, then, is the explanation for the different feelings which your two hands bring you?

Why Your Hands Felt Hot and Cold

There is but one conclusion. The sense of touch does not always tell us how fast molecules are moving. In trying to feel the dance of the molecules, we are too much influenced by the last thing we touched. If an object is hot enough to burn us, or cold enough to freeze us, our sense of touch will give us warning. Beyond that, however, touch is very unreliable as a means of measuring the speed of the molecular dance.

Perhaps you have seen a fond mother place her hand on a child's forehead when she suspects that the child is feverish. Sometimes her touch tells her that the head is warmer than it should be, and sometimes it does not. It all depends upon where her hand has been before she laid it on the child's forehead. If she is a wise mother, she will not rely upon her hand, but will use a thermometer; for a thermometer is the only accurate method of measuring the speed of moving molecules.

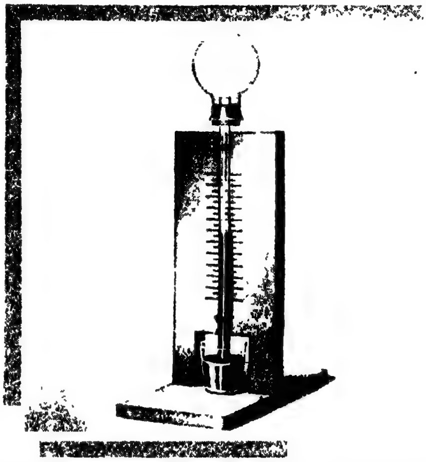
If we wish to know how fast a train is moving, we time the train as it passes over a certain known distance. To do this in the case of a molecule is impossible. Another method is necessary.

In a preceding story we learned that warming objects causes them to expand—which means that the faster molecules move, the more space they occupy. This is not hard to understand, for the molecules, since they are moving faster, collide with greater force and therefore bound further away from one another. Thus, if we can measure the space occupied by an object while hot and compare it with the space occupied when the object was cold, we can tell something about the amount of increase in speed of the moving molecules.

This method was used more than three hundred years ago, though no one at that time knew anything about molecules. Scientists of that day spoke of warm objects as containing a certain number of "degrees of warmth." This idea of "degrees" has remained to the present. Instead of measuring molecular speeds in "miles per hour" we still measure it in "degrees of temperature." The instrument which does the measuring is called a thermometer.

In the seventeenth century, a Dutchman

named Drebbel made a thermometer which consisted of a flask with a long narrow neck. The flask contained water up to a certain point in the neck. If placed near a warm object, the water in the flask soon grew warm and expanded. This was indicated by a rise of the water level in the neck. The higher the temperature, the higher the rise of the water level. In some ways this first thermometer is not very different from the one we use today. Our thermometers resemble flasks with long necks, and they contain a liquid. The liquid is not water, however; it is usually mercury.



Here is an air thermometer which anyone can make out of a round glass flask, a cork, a glass tube, a common tumbler, and a few pieces of wood.

Galileo (găl'ĭ-lē'ō), who practiced medicine at one time in his life, needed some way to measure the fever of a patient. He knew that heat expands gases more than it does liquids. He therefore decided to use air in his thermometer. This consisted of a glass flask with a long neck; but it was filled with nothing but air. It was inverted with the open end immersed in a jar of water. To prepare it for use, Galileo first heated the flask to expand the air in it a little. This caused a few bubbles of air to escape from the open end under the water. Upon cooling, the air contracted again, and the water level was pushed up by air pressure to a point up in the long narrow neck. Now, if the flask of air was brought in contact with the body of a patient, the bodily heat expanded the air and pushed down the water level. The higher the temperature, the greater the depression. This thermometer proved to be very sensitive. It responded quickly and noticeably to small changes in temperature; but of course it was not very accurate, and it is no longer used in our day.

In 1630, Jean Roy (zhôN rwå), a Frenchman, made a thermometer on the style of Drebbel's, but he used alcohol instead of water. This was an improvement, because alcohol expands more readily than water and freezes at a lower temperature. An alcohol thermometer can be used for temperatures at which a water thermometer would cease to work because the water in it would be frozen and would break the glass.

Ten years after Roy had made his alcohol thermometer, the Grand Duke of Tuscany introduced an improvement by sealing the long neck of Roy's thermometer in such a way that all the air was excluded. This made measurements much more accurate. For the next hundred years, scientists interested in thermometers were not so much concerned with further improvements of the instrument as with the problem of deciding upon a scale of units to mark on it. Of what use is a yardstick if those who use it cannot agree upon what shall be called "an inch"? Similarly, it was necessary to decide upon what should be a "degree" of temperature. Furthermore, what temperature should "hot" be? What temperature should "freezing" be? What should be the temperature of the normal healthy body?

How We Measure Temperatures

On other pages of these books we have told how these problems were finally solved, and how we came to have our Fahrenheit and centigrade thermometers of to-day.

As was said once before, we cannot measure the speed of molecules in miles per hour; but if we know the substances of which an object is made and its temperature, we can get a pretty good notion of its molecular motion. Because we have grown accustomed to thinking in terms of "degrees" of temperature, it will be more interesting to learn exactly how hot or how cold certain things are. The scale we give answers a number of

questions which the reader may have asked at one time or another.

The thermometers used most frequently in everyday life all contain a liquid, such as mercury or alcohol, which expands when it is warmed. But gases and solids also expand when heated and can also be employed. We have already mentioned the thermometer invented by Galileo, in which air, a mixture of gases, was used as the expanding substance. Although subject to many errors, Galileo's air thermometer has many things to recommend it. In fact, a somewhat similar thermometer using hydrogen gas has been adopted by scientists for very accurate measurements of temperature. Convenience, rather than accuracy, is what made the liquid thermometers so popular.

What an Oven Thermometer Is

Because of convenience, also, solids have been used as the expanding substance in thermometers. The most common form of this type of instrument may be found in the baking oven, where the high temperatures would raise mercury or alcohol beyond their boiling points.

An oven thermometer consists mainly of a coiled metallic strip. This strip is usually a compound bar; that is, it is composed of two strips of different metals, brass and iron, riveted or welded together. Since one metal expands more readily than the other, the coil tends to open up when the temperature rises and to contract when the temperature falls. The movement of the coil turns a pointer over a dial on which a temperature scale is marked. This scale is in accordance with an accurate thermometer of some other type. There are two chief advantages of the "metallic" thermometer. In the first place, it makes possible the measurement of much higher temperatures than do the liquid thermometers. In the second, the pointer moving over the large dial is more easily observed. No squinting at a thin thread of mercury is necessary. The temperature reading is as visible as the time on the face of a clock.

The Weather Bureau often wishes to know how the temperature of the air changes from hour to hour during several days or even a week. It would be too much trouble and expense to keep a man watching the thermometer all the time. And so a "self recording" thermometer is used. This is how it works:

The essential part of the instrument is a solid metallic coil like the one used in the oven thermometer described before. Instead of moving a pointer over a dial, however, the expanding and contracting coil moves a long lever. At the end of this lever is a pen point filled with a supply of ink. The pen touches a sheet of paper upon which it makes a mark. Now this sheet of paper is ruled off into vertical columns. The width of each column represents an hour of time, and there are enough columns to make up a whole week. The paper is also ruled with horizontal lines and the space between lines stands for one degree of temperature. Printed in a vertical column are the numbers of the temperature scale, and printed horizontally across the top are the names of the days of the week. The entire sheet fits exactly around a cylinder which is moved by clockwork just fast enough to carry the sheet completely past the pen point in the course of a week. In this way an ink line is marked across the sheet. When the temperature goes up, the line rises; when it goes down, the line drops. Faithfully and steadily, and without requiring any special attention, the pen draws this line from minute to minute, always showing what the temperature is at any moment and leaving behind it a record of what the temperature was an hour ago, six hours ago, or two days ago.

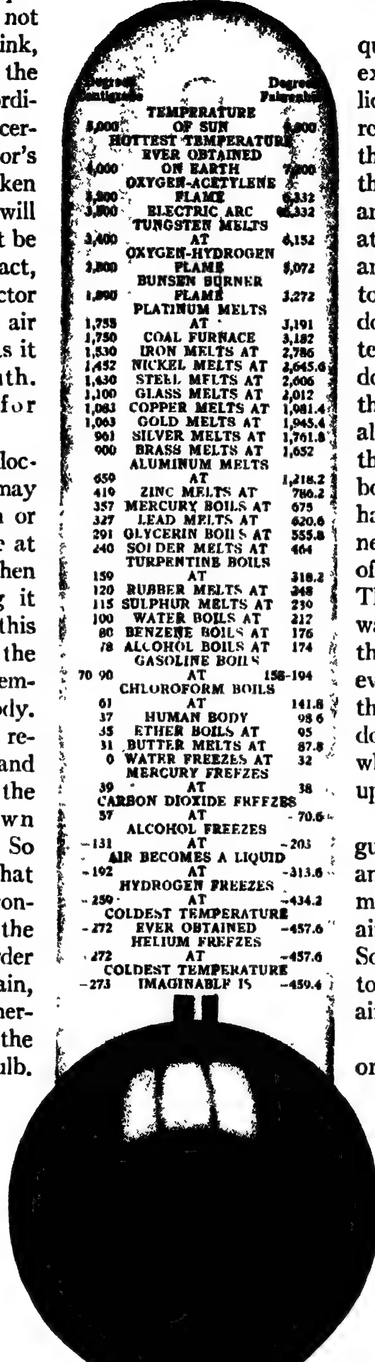
Recording Conditions at a Great Height

This same type of recording thermometer is used when aviators explore the upper reaches of the atmosphere or when a sounding balloon is sent twenty-five miles up into space in order to find out what conditions are like at such a great height. The thermometer makes an ink-line record of the temperature changes on the way up and down.

A doctor's thermometer is rather interesting. You can take it from a patient's mouth into the coldest room and keep it there for hours; but it will continue to show

the temperature of the patient's body. Why does not the mercury cool and shrink, and draw down the level of the liquid in the stem? An ordinary thermometer would certainly do so; but a doctor's instrument must be shaken sharply before the mercury will drop and let the instrument be used a second time. In fact, we all know how the doctor snaps the little tube in the air several times before he puts it into the patient's mouth. What is the reason for this?

If you look closely at a doctor's thermometer you may notice a sharp constriction or pinching of the inside tube at the bottom of the stem. When the mercury is expanding it forces its way up through this narrow channel, rising to the point which indicates the temperature of the patient's body. When the thermometer is removed, the mercury cools and shrinks, but the liquid in the stem cannot pass down through the constriction. So the highest temperature that the thermometer indicated continues to be registered by the mercury in the stem. In order to use the instrument again, one must shake down the mercury, so that the liquid in the stem joins the liquid in the bulb.



We sometimes read in the newspapers that "the lowest temperature reached during the night was ten degrees below zero." Did some person stay up all night taking measurements every five minutes or so? Of course not. The newspaper or the Weather Bureau used an instrument called a "minimum thermometer."

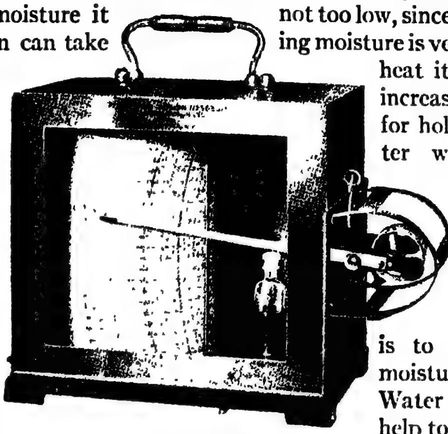
Such a thermometer frequently contains alcohol as the expanding or contracting liquid. A small iron "rider" rests inside the stem just at the top of the liquid. When the alcohol gets cold, it shrinks and drops. There is sufficient attraction between the alcohol and the surface of the iron rider to cause the rider to be dragged down too. The colder the temperature gets, the further down the rider is dragged. As the temperature goes up, the alcohol expands and rises in the stem; but the rider is left behind. If the thermometer has been left out all night, we need only look at the position of the rider in the morning. This will tell us how cold it was during the night. To use the theromometer again, however, we must lift the rider to the top of the alcohol. This is done with a horseshoe magnet which can pull the iron rider upward.

In recent years we have begun to realize that our health and comfort depend just as much upon the moisture in the air as upon the temperature. So it is important to know how to measure the humidity of the air.

Before we describe how two ordinary thermometers can be used for such measurement let us say a few things about humidity. First, it is important to remember that our bodies are continually giving off moisture to the air through the pores in the skin. This is necessary because the body must get rid of excess heat in order to keep itself at the nor-

mal temperature of 98.6° Fahrenheit. Evaporation of moisture from the skin carries away a great deal of heat. Secondly, the rate of evaporation depends upon the concentration of moisture already in the air. If the latter is dry, skin evaporation is rapid and may chill the body. Should the air already contain all the moisture it can hold, no skin evaporation can take place. In that event, the body gets warmer and warmer and may, in extreme cases, cease to function altogether.

Now how much moisture can air hold? That depends upon the temperature of the air. Warm air can hold more than cold air. The scientist compares the amount of moisture which the air in a room contains with the maximum amount it can possibly hold at that temperature. This ratio he calls the "relative humidity." Thus if the maximum amount which a room at 68° Fahrenheit can hold is 80 pounds, and if the room actually contains but 40 pounds, the relative humidity is 40 divided by 80, or 50 per cent. On the Sahara Desert, the relative humidity may be as low as 10. This means that the desert air contains but one-tenth of the moisture which it can hold. On a warm, muggy day in a New York summer the humidity may be as high as 95. In this case the air contains almost the maximum amount of moisture which it can possibly hold. Such air is extremely uncomfortable; yet it is less dangerous to health than is an indoor humidity of 10. In a room of that humidity the skin gets arid, the body is chilled, and the lining of nose, mouth, and throat crack from dryness, thus furnishing excellent breeding places for disease germs. Engineers tell us that a relative humidity of from 40% to 60% is best for health and comfort.



This instrument is a "thermograph." It keeps track of the temperature for every second of every day for a whole week. If the clock is wound every week, the device will continue to record the temperature indefinitely, provided you keep the pen filled with ink and replace the paper chart every week. You will notice the long arm carrying the pen point, which rests against the chart. The chart is marked off in days of the week and hours of the day, and is wrapped around a cylinder which is moved by clockwork.

Unless our houses are provided with the latest machinery for "air conditioning"—which means keeping the air just warm enough and moist enough—indoor air is likely to get too dry in winter. This is due to the fact that we heat our homes without adding moisture to the air. Outdoor air on a very cold day usually contains little moisture; yet its relative humidity is not too low, since its capacity for holding moisture is very low. But when we heat it for use indoors, we increase greatly its capacity for holding evaporated water without adding any water at all. As a result, our living room often becomes drier than the Sahara Desert. The only remedy is to see that additional moisture gets into the air. Water pans on radiators help to some extent; but the only really good means involves expensive air-conditioning machinery.

In order to know when more moisture is needed in the air, we must find a way to measure relative humidity. This is accomplished with a "wet- and dry-bulb" thermometer. It consists of two thermometers, one with its bulb dry and the other with its bulb surrounded by a wick which dips into a reservoir of water. The dry-bulb thermometer tells us the room temperature in the usual way. The wet-bulb instrument usually reads lower than the dry, since the evaporation of moisture causes the mercury to cool. The faster the evaporation, the greater is the cooling effect. Since dry air results in rapid evaporation, the wet-bulb thermometer reads very much lower than the dry one in a very dry room. If the room is so humid, however, that its air already contains all the moisture it can possibly hold, the two thermometers read exactly alike. So the difference in their readings is a measure of the relative humidity.

PHYSICS

Reading Unit No. 15

HOW DOES HEAT TRAVEL?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Conduction, 1–395-97
Heat insulators, 1–396
Convection currents, 1–397-98
Radiation, 1–399-400
Heat from steam radiators, 1–397-98
Heat from the sun, 1–399-400
What keeps things hot or cold in a thermos bottle? 1–400
How pot handles are kept cool enough to hold, 1–396

Things to Think About

Why does the handle of a poker grow hot?
Why can we heat ice in water without melting the ice?
Why does hot air rise?
Why are the walls of thermos bottles silvered?

Picture Hunt

How can the heat conductivity of solids be tested? 1–397
How does warmed air travel through a heated room? 1–398
How does a fireplace transmit the heat of its fire? 1–399

Related Material

How does steam travel through a heating system? 1–479-80, 10–382
How do clouds form? 1–235, 407
How are winds produced? 1–222-25, 399
How do convection currents help to scatter seeds? 7–214
How do convection currents help to spread hay fever? 2–111, 113, 145
How do convection currents distribute hot water in a hot-water system? 7–484
How have the Dutch put convection currents to work? 6–345, 352
How do ocean currents move? 5–173

Practical Applications

How are pot handles kept cool enough to hold? 1–396
How are rooms heated? 1–398-99

Leisure-time Activities

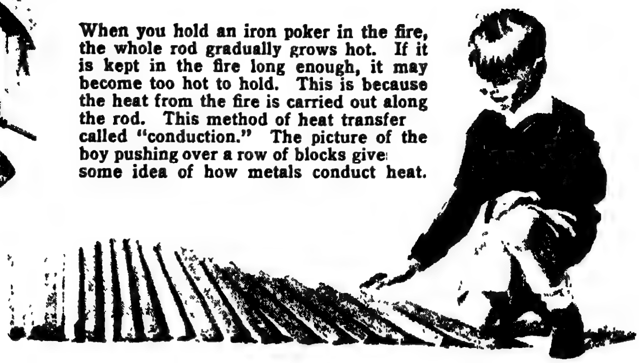
PROJECT NO. 1: Construct a device to show the ability of different substances to conduct heat, 1–397.

PROJECT NO. 2: Show your friends how you can boil ice water without melting the ice in it, 1–397

Summary Statement

Heat is transmitted through solids by conduction, through fluids and gases by convection, and through space by radiation.

When you hold an iron poker in the fire, the whole rod gradually grows hot. If it is kept in the fire long enough, it may become too hot to hold. This is because the heat from the fire is carried out along the rod. This method of heat transfer called "conduction." The picture of the boy pushing over a row of blocks give some idea of how metals conduct heat.



When the boy pushes the block nearest him, he is doing about what the fire does when it causes the molecules at one end of the iron poker to increase their dance. These molecules bump into their neighbors, which in turn bump into still other molecules. Before long the molecules in the entire rod are dancing more vigorously than they did before - even those next the hand that is holding the iron poker.

HOW DOES HEAT TRAVEL?

If the Warmth from a Radiator Goes Upward, Why Does It Heat the Whole Room, and Not Merely the Air Just above the Radiator?

MR. NELSON and his little son John were sitting before the fireplace chatting about many things while roasting chestnuts in the hot embers on the hearth. John managed the metal poker and his father prepared the delicacies for the fire. In a little while John remarked that the poker was getting too hot to hold. He wondered why the rod should get hot so far from the fire, when the handle on a teapot, shorter and much nearer the gas flame, never grows too hot to hold. He asked his father to explain.

"Well," said Mr. Nelson, "as I look around me, I find that you and I are receiving heat in three different ways. The poker illustrates one of these ways, the steam radiators another, and the fireplace a third Suppose we look into all three of these ways of receiving heat energy. You will find that the poker method is, after all, very simply explained. The other two are not so easy to understand. However, I am ready to try, if you agree to listen carefully and to ask questions. Shall we start?"

John agreed and his father began. "As for the poker, you must remember that it is composed of molecules (mŏl'ĕ-kūl). So is every other piece of matter on the earth. Now these molecules are never still; they are constantly quivering. The hotter the poker, the more rapidly the molecules dance back and forth. The end of the rod which is in the fire is, of course, the hottest part of it. There the dance is indeed violent. But what about the molecules that are just outside of the fire? Can they maintain a slow movement while their neighbors speed up? Certainly not; for they are constantly banged by the violently active molecules. Pretty soon, they too are moving faster, causing a disturbance among their next neighbors. It is like a line of blocks each one of which is resting against the one in front. Push the first one in the line, and the push is transmitted through each one in turn, until it reaches the last in the line; and the last one is pitched forward. In the same way, rapidly quivering molecules transmit movement to their neighbors; these, in turn, hand

on the energy to those just beyond, until the entire poker contains molecules that dance more actively. When the molecules of the part of the poker you are holding begin to quiver at greater speed, you complain that the poker is getting too hot to hold. The scientist explains all this by saying that your hand has received some of the heat from the fire by 'conduction' through a metal rod."

"But what about the handle on the teapot?" exclaimed John. "Can't the heat from the gas flame be conducted through the pot to the handle?"

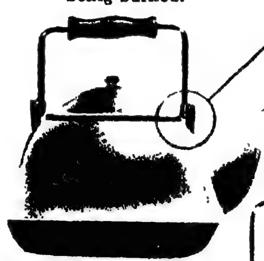
"Yes," said his father, "it is; but very slowly. I ought to send you to the kitchen to look at the teapot; for I'm afraid you haven't been observing carefully. Can you recall anything different about its handle?"

"Yes, I can. Now that I think of it, the metal handle is separated from the body of the pot by two black pieces of some sort of material. I have always wondered why a solid handle was not used and why it was not fastened directly."

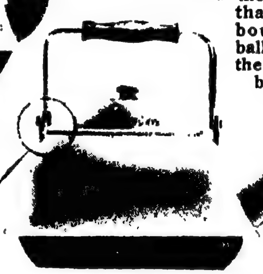
"What you call the black pieces is the secret of your mystery. They are made of hard rubber and are called 'insulators' (ĭn′sû-lā′tẽr). It has been discovered that the molecules of such substances are not easily excited into motion. In other words, they do not conduct heat readily."

"Is hard rubber the only substance that does not conduct heat very well?" asked John.

In the teapot below, the wire in the handle is connected with the pot by a strip of nonconducting material. This is shown inside the little circle. When the pot gets very hot and its molecules are dancing furiously, those molecules pound into the molecules of the nonconductor. The latter, however, are not easily set in motion and do not hand on this motion to the molecules of the handle. So one can lift the teapot without danger of being burned.



A dancing molecule will have no more effect on the nonconducting material between the handle and the teapot than this bouncing ball has on the back-board.



When a dancing molecule comes in contact with a good heat conductor, it passes its energy on—just as a ball does when it hits a net.

In this case, the teapot handle is connected directly with the metal of the pot. When the metal is hot, its rapidly dancing molecules can hand on their energy to the wire handle, which soon gets too hot to hold. In other words, the heat of the pot is readily conducted to the handle. Even the wooden spool around the wire frame may not be enough to keep the heat from reaching the hand.

"Not at all," replied Mr. Nelson. "Let me show you another poor conductor. Do you see this medicine dropper? I remove the rubber bulb, so that I now have only the glass left. Now, you take this iron nail. Let us both put what we hold near a hot coal. The one who holds on longer wins the contest."

John accepted the challenge. The nail and the glass tube were both held near the coal. John held the end of the nail for some time; but before very long the metal grew so hot that he was compelled to let it go. His father, on the other hand, seemed to feel no discomfort at all in holding the glass.

"Glass is a very poor conductor of heat," said his father; "that is why I won. Wood, too, is a poor conductor. So are asbestos, cotton, wool, paper, and sawdust. All metals are good conductors, though some are better than others.

"Now can you tell me, John, why the bathroom floor feels so cold to the feet, while the rug on it, though just as cold as the floor, feels warm?"

How Substances Conduct Heat

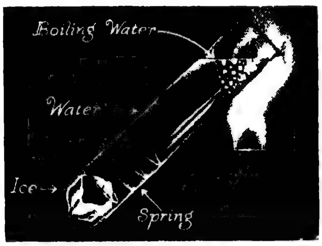
"Why," said John, "I have always had the idea that the rug was warmer than the floor."

"No, not at all," said Mr. Nelson. "Both floor and rug are in the same room and in contact with each other. Whatever is the temperature of one must be the temperature

of the other. Yet you know well enough that one feels warmer than the other. Why?"

"Is it because the rug is a poorer conductor of heat than the tile?"

"Right!" was the reply. "The tile carries heat away from your feet by conduction; so that they feel cold. The rug, on the contrary, carries away very little."



Water is a poor conductor of heat. In the test tube at the left a flame is boiling water at the top of the tube. At the same time a piece of ice, held down by a spring, remains unmelted at the bottom. At the right is a photograph of some crude asbestos, a mineral which is a very poor conductor of heat.

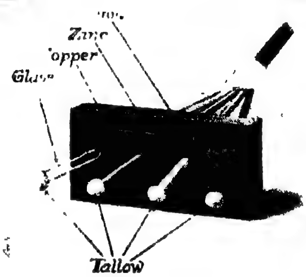
"What's the poorest heat conductor in the world?" asked John.

"If you can think of a place where no molecules exist, that place will be the poorest heat conductor, since there will be nothing to hand on the motion of the molecules. Ordinarily, we call such a place a vacuum. However, a perfect vacuum is hard to maintain on the surface of the earth.

"Next to a vacuum, I should say that air is the poorest heat conductor. Air spaces in clothing and in the walls of houses help to hold heat in and to keep outside heat from getting in. Liquids also are poor conductors. In solids, the molecules are so closely packed that they tend to hand on their motion from one end of the substance to the other."

"I think I understand now how heat travels by conduction," said John, "but didn't you say there were two other ways by which heat may travel from one place to another?"

At this point Mr. Nelson asked John to look at the radiator at the farther end of the room. "How is it," he said, "that the radiator over there can keep us warm even when the fireplace is not going? The air which separates us from the radiator is one of the poorest of heat conductors. The rapidly dancing molecules of the hot metal cannot and do not transmit their movement through the long line of air molecules between the metal and our bodies. And yet, as you see, the radiator does heat the air which surrounds us."



Among the four rods shown in the picture, which is the best and which is the poorest conductor of heat? Each has a piece of tallow on one end. The other ends come together in the flame. You might try this experiment in your home laboratory.

They went over to the radiator and Mr. Nelson stood by for a while, puffing his pipe. Then he blew a cloud of smoke across the top of the heater. The cloud spread quickly, but most of it was at once carried upward toward the ceiling. A second puff, discharged in another direction, spread more rapidly than it rose. This difference impressed John.

"It seems," he said, "as if a wind were blowing up from the radiator."

"Yes, it is a wind," was the reply. "Bring down that pin wheel I saw in your room to-day. Perhaps this wind can turn it."

Why Hot Air Rises

When John brought the paper toy, his father placed the stick on the radiator. The wheel turned continuously, stopping only when it was removed.

"That radiator certainly causes a steady wind upward," remarked John. "I suppose it is because hot air rises."

"So it does," was the reply; "but why?"

After some discussion of this, John began to see that several things were happening.

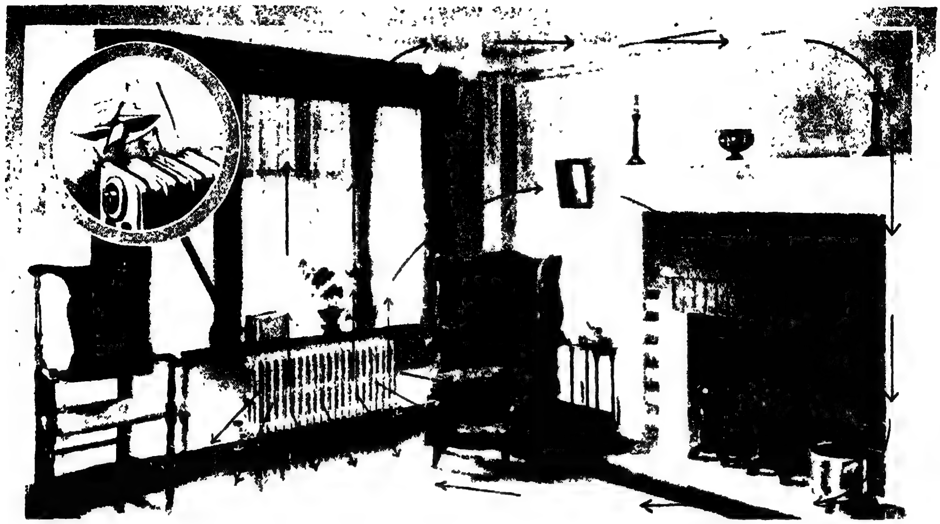


Photo by American Radiator Company

Another method of heat transfer is known as "convection." The arrows in the picture above show how the air, when warmed by the radiator, rises and circulates about the room. If you were to mount a pin wheel on the radiator, the pin wheel would be turned by the upward rush of heated air. The straight arrows pointing downward from the radiator represent the third method of heat transfer—namely, "radiation."

First, the air molecules touching the radiator molecules were taking up the rapid dance by conduction. Secondly, this air expanded in volume because it was becoming warmer. Thirdly, the expanded air was lighter than the colder and therefore less expanded air about it. Fourthly, this lighter air floated upward toward the ceiling for the same reason that a cork floats to the top of a jar of water. Finally, as soon as this air floated upward, new air took its place, became warm, and floated upward too.

What Is a Convection Current?

In this way the hot radiator was responsible for a steady upward stream of air.

"What happens to all the heated air that is being sent toward the ceiling?" asked Mr. Nelson.

"Why," replied John, "it can't all stay there. There is too much of it. It is pushed along by the newly warmed air coming up from the radiator. After a while, there will be so much warm air that the cold will be crowded out."

"But you forget that the cold air must take the place of the warm air that rises. In fact, a circulation is set up. The cold air is pushed toward the radiator. There it is heated, and caused to rise. So long as the radiator is hotter than the air, the air will flow in a current—up from the hot point, around the room, and along the floor back to the hot point again. Such a flow is known as a 'convection' current.' It is the second way in which heat may travel from one place to another."

John and his father now returned to the fireplace, and talked about this new idea of convection. John soon learned that convection currents are set up in water as well as in air. Warm water rises for the same reason that warm air rises. He was told that there is a circulation of water in a teakettle being heated on a stove, and that houses are sometimes heated with circulating hot water rather than with steam. In this case the boiler, pipes, and radiators are completely filled with water. The furnace heats the water in the boiler till it expands and rises. Cold water takes its place, and when heated joins the upward stream. Soon the radiators in the rooms upstairs are filled with hot water that sends its warmth into the air.

Many other interesting facts about con-

vection were mentioned by John's father as the conversation continued. Some of them John understood at once. Among these was the fact that the winds which bring changes in weather are really huge convection currents in the earth's atmosphere, resulting from unequal heating of the earth's surface by the sun. Another was the fact that in an ice box a reversed convection current, caused by the cake of ice or cooling coil, bathed platters of food in cold air. But there were other facts arising in the discussion which John did not grasp so well. To these he resolved to give some further study. He made up his mind to visit the cellar of his house the very next day, in order to see for himself how the boiler caused cold water to get warm and then rise to the hot water faucets upstairs. Also, he intended to read about the Gulf Stream, which, according to his father, was a huge convection current in the waters of the ocean.

"How about the third method of transmitting heat?" asked John.

"Well," replied his father, "just look at the glowing log in the fireplace. Are we getting heat from it?"

"Of course, I can feel it on my face."

"Do you get it by conduction or convection?'

"Let me see It can't be by conduction, because air molecules do not hand on their motion easily; that is, air is a poor heat conductor. It might be by convection, but the current of air starting from the log goes straight up the chimney and never reaches my face. How *does* the heat of the log get to my face?"

"Evidently, John, you see the problem. You will note that the air between the log and your face is in no way concerned in bringing heat from the log. There might even be a vacuum there, and the heat could reach you just the same. Has it occurred to you that we receive heat from the sun, ninety-three million miles away, across space which is certainly a vacuum? And you surely know that a lighted electric lamp is too hot to touch, even though the heated filament is surrounded by a vacuum."

The heat which you feel on your face as you sit before a fire comes to you, not by conduction or by convection, but by radiation. The circular lines are meant to indicate heat waves.

"Your mentioning the sun's heat makes me think that perhaps we receive rays of heat, just as we receive rays of light. Is that the third method of carrying heat?"

"Why, yes! That is it exactly. We receive heat by 'radiation.' Practically all hot bodies radiate heat rays or heat waves, as the scientist calls them. We do not understand altogether what these waves are, but we know that somehow heat energy travels from one place to another through space that is completely devoid of molecules of any kind. It is one of the strangest facts of science, that in spite of our lack of understanding of the nature of these waves—if they are waves—can measure their speed of travel, study their effects upon the matter that they strike, and control their behavior in many ways."

This little device, often seen turning in opticians' windows when the sunshine strikes it, is known as a "radiometer." In the picture we see it being turned by heat waves from a lighted candle.

The Waves the Sun Broadcasts

"What you say makes me think of a radio broadcasting station. The sun is a great broadcaster, sending all kinds of waves out into space. Some of these waves enter our

eyes and we call them light waves. Others strike our bodies and we feel them as heat. Is that it?"

"Yes, that is about it. And the sun is broadcasting many other kinds of waves which our bodies neither see nor feel because we have no senses with which to receive them."

Mr. Nelson thought it wise at this point to conclude the conversation with his son and send him to bed; but in doing so, he promised to perform an interesting heat experiment some time soon.

The chance for the experiment came a day or two later. Mr. Nelson asked the boy to come to the kitchen, where he took a thermos bottle from the shelf and filled it with hot water. At the same time he filled an ordinary milk bottle with water equally hot.

The Inside of a Thermos Bottle

"Let's leave these bottles alone for a while," said he.

They returned in about an hour with a thermometer. Taking the temperature of the water in both bottles, they discovered that the water in the milk bottle had lost most of its heat, while that in the thermos bottle was still quite hot.

"What is there about a thermos bottle," asked Mr. Nelson, "which prevents the heat from escaping so readily as it does from an ordinary bottle?"

"Can we take the thermos apart?" asked John.

"Let's try."

Under the careful guidance of Mr. Nelson, John unscrewed the cap and took out the cork. Pouring out the hot water, he removed the glass bottle from its metal container.

"This looks like a double bottle, one inside the other and joined to it at the neck. Is there anything between the walls?"

"No, nothing except three little wedges that keep the inside bottle from swinging and thus breaking at the neck. Even the air has been removed. You can tell this by the peculiar, drawn-out point at the bottom. Evidently this point was sealed off in a flame after a pump had sucked out the air. If the point were broken, air would rush in through the opening to fill the space between the bottles."

"Another thing that seems unusual is the fact that the bottle seems to be silvered on the inside. It looks like a mirror."

How the Thermos Works

"Yes; and I might say that the inside bottle is also silvered. You can see this by looking into the container part of the double vessel.

"Now, John, can you find a good reason for each peculiar feature of the thermos? Remember that heat from the hot water inside can leave in three ways, by conduction, convection, and radiation. Take them one at a time and see if there is some part of the bottle which prevents or retards the escape of heat."

"I can explain how conduction of heat is slowed down," said John. "The hot water touches glass and glass is a poor conductor of heat."

"Very true; but the hot water in the milk bottle touched only glass, too."

"Well, about convection then—the hot water is surrounded by a vacuum. Hence there can be no convection currents to carry heat away."

"Fine! Now find a way of preventing radiation."

Why We Put Mirrors in a Thermos Bottle

John pondered over this for some time and then realized that he had as yet found no purpose for the silver mirrors. Mirrors reflect light rays. Can they also reflect heat rays? That must be it! "The outer silvered bottle reflects the heat radiations from the hot water back into the water," he exclaimed.

"Splendid! Now one more thing; why should the inside bottle also be silvered?"

"Perhaps," said John, "that is to keep out heat radiations from the outside which try to get in. I know that a thermos can keep liquids cold as well as hot."

"That tells the whole story," said Mr. Nelson.

PHYSICS

Reading Unit
No. 16

BOILING, CONDENSING, MELTING, FREEZING

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Solids, liquids, and gases, 1–403-4
When do solids melt? 1–403
Boiling points, 1–403
Cooking under pressure, 1–404
Manufacturing liquids from gases, 1–406
How radiators become hot, 1–406-7
What cools objects? 1–408-9
Dry ice, 1–409

Things to Think About

Why does water boil at a lower temperature on top of a mountain than at its foot?
How may air be liquefied?
Why does a kettle of liquid air boil on a cake of ice?
How may objects be cooled by means of heat?

Picture Hunt

How does one blow both warm and cold? 1–408
How is dry ice made? 1–406
What happens to the molecules in a solid as it changes to a liquid or a gas? 1–403

Related Material

How are meats preserved during transportation? 9–329
How are foods preserved while in transit? 10–518
How is electricity used for refrigeration? 1–410, 10–518
What does freezing do to the volume of water? 1–483
How does condensation cause rain? 1–244-46, 407
How is the principle of melting used in industry? 9–398, 401
How is the principle of boiling applied in steam boilers? 10–397
How do snow and hail form? 1–249, 251-54
Where is ice red-hot? 1–155

Practical Applications

How are foods preserved by boiling, condensation, and freezing? 1–408-10
How has the melting of metals affected the course of civilization? 1–407-8

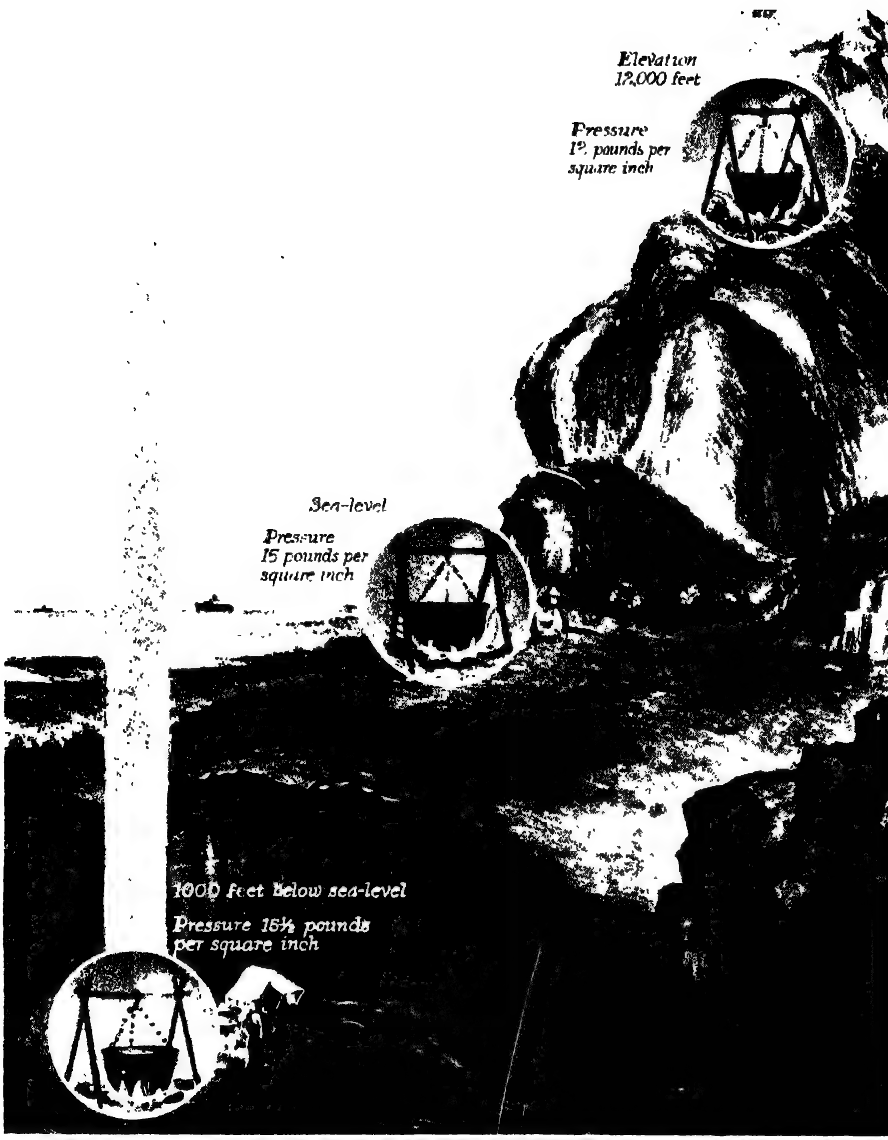
Leisure-time Activities

PROJECT NO. 1: Show your friends that you can make your breath both cold and warm, 1–408.

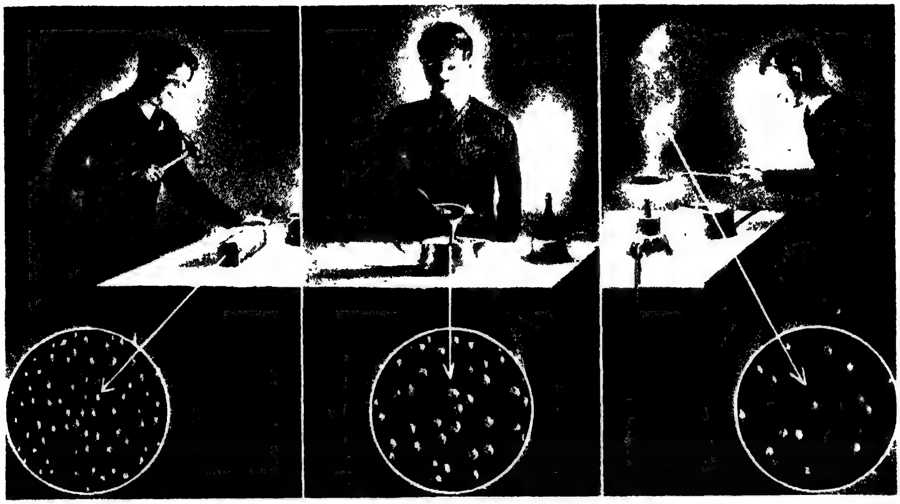
PROJECT NO. 2: On a mountain climb show your friends that water can boil below its usual boiling point.

Summary Statement

Weather prediction, refrigeration, and the science of metallurgy all depend upon an understanding of the principles underlying boiling, condensing, melting, and freezing.



A party of mountain climbers started out from a valley 1,000 feet below sea level. There are not many such spots on earth, but there are a few. When they tried to boil water the first day out, they discovered that it took them a long time, for though they did not realize it, upon the surface of the water there was resting a shaft of air 1,000 feet longer than at sea level. This added about a half pound per square inch to the normal air pressure, and water had to be above the usual boiling point before it would boil. Later the party reached sea level, where the pressure of the air is about 15 pounds per square inch. There water boiled at the usual temperature of 212° F. Continuing their climb, they finally reached an elevation of 12,000 feet above sea level. The shaft of air pressing down upon the water in the pot was now a good deal shorter in length, and so weighed less. Under an air pressure of about 12 pounds per square inch the water boiled at so low a temperature that they found it difficult to boil an egg hard.



Raising the temperature of an object causes the molecules in it to dance faster. In the first picture the boy is warming a solid bar of metal by pounding it with a hammer. The metal grows hot and the molecules are made to dance faster, but they are still so closely packed that the bar keeps its solid form. In the second picture the heat of a torch has been applied to the metal and has melted it. When the metal is in the liquid state the molecules in it not only dance faster but are much farther apart. In the third picture the molten metal is being boiled, and so is changing to a vapor. Here the dance of the molecules is most furious and the distance between them is greatest.

BOILING, CONDENSING, MELTING, FREEZING

Here We Tell of Some Interesting Things That Happen with the Kind of Energy We Call Heat

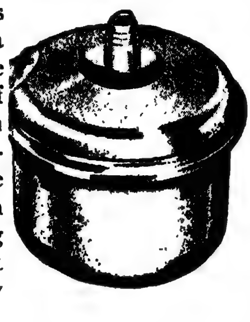
LET us imagine a ship that can travel anywhere in space, and let us place on board a party of travelers belonging to some distant solar system. These men have come to visit our own solar system in order to observe the sun, the earth, and the moon. They note at once how different in size these bodies are, and especially how much hotter one is than the others. They are sure to notice, too, that the sun is entirely composed of gases and the moon of solids, but that on the earth there are both gases and solids, and liquids besides. We may be sure that such observers from space would be attracted to the earth in order to find out more about it. They would be interested in discovering why gases, liquids, and solids can exist side by side and why a piece of matter changes from one of these states to another.

The longer the party stayed, the more surely would they learn that each change of state is accompanied by a transfer of energy from one place to another. They would learn that the plants and animals which inhabit the earth depend upon these changes from solid to liquid, liquid to gas, gas to liquid, and liquid back to solid.

We who live our lives upon the earth, seldom realize how basic these changes are to our existence. Perhaps if we viewed the changes somewhat as visitors from another heavenly body, we might be in a better position to understand and appreciate their importance.

The very first thing we must get clear is the difference between a solid and a liquid and between a liquid and a gas. A solid is a quantity of matter which under normal conditions on the surface of the earth has a

definite volume and a definite shape. A lump of sugar, a steel girder, a pencil, a coin, are all familiar examples. A liquid is a quantity of matter which, under normal conditions on the surface of the earth, has a definite volume but no definite shape. A liquid tends to take the shape of the vessel which holds it. Thus, a certain quantity of milk may take the shape of a milk bottle, a glass, or a pot. A gas is a quantity of matter which, under normal conditions on the surface of the earth, has neither a definite volume nor a definite shape. For example, we all know that a certain amount of illuminating gas, released from a jet, fills the room; and if the window is open, spreads into the whole outdoors. The only reason why the gaseous air surrounding the earth does not spread out through space is that the gravity of the earth prevents its escape.



In a pressure cooker the steam is not allowed to escape. The molecules in the steam pound down upon the liquid, retarding somewhat the boiling off of new molecules. This results in a raising of the temperature at which the liquid boils.

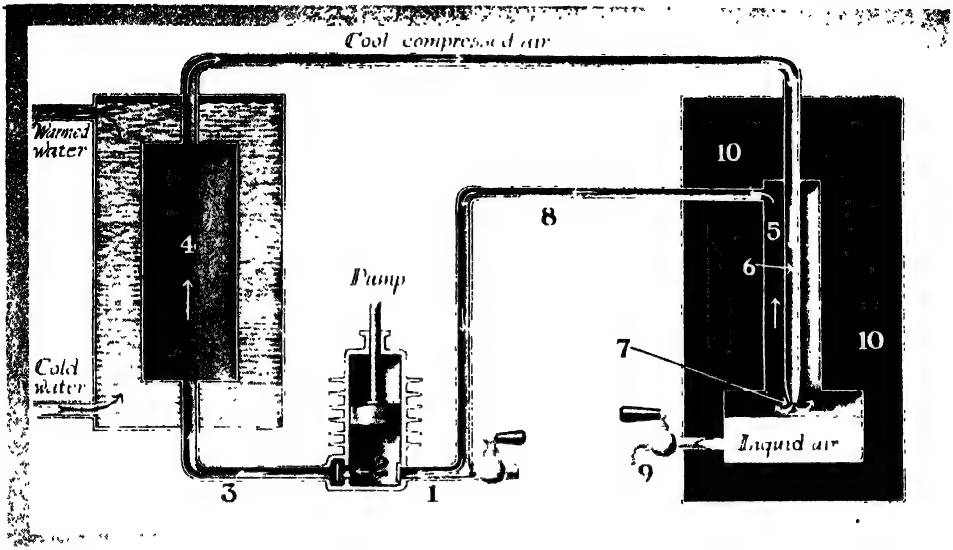
Recalling the fact that all matter is composed of molecules (mŏl'ē-kūl) in motion, we may say also that in solids the molecules are most closely packed together, while in gases they are most widely spread apart. Furthermore, molecular movement is much freer in gases than in liquids and freer in liquids than in solids. Let us recall, too, that raising the temperature of a body causes its molecules to move faster.

The Action of Heat on Water Molecules

If we wish liquid water to change into gaseous water—that is, into steam—we add heat to the water. How does this added energy operate? First, the water molecules are made to move faster. Second, the more rapid motion results in a greater number of collisions among the molecules. Third, these collisions near the surface cause some of the molecules to be kicked off from the liquid into the air above. As more heat is added, more molecules tend to leave the liquid. Finally, when the boiling temperature is reached, large groups of molecules separate in the liquid, float to the top as bubbles of steam, and escape into the air. If still more heat is added, it increases the amount of steam liberated; but it does not increase the speed of the water molecules. Another way of saying this is to say that the temperature does not increase after the boiling point is reached. Not until all the liquid water is gone, does the flame tend to raise the temperature of the steam above the boiling point, or 212° Fahrenheit.

Now when the water molecules escape, they must find place for themselves among trillions of air molecules. As a matter of fact, the air molecules are themselves constantly pounding down on the surface of the liquid. The pressure which this pounding causes restrains somewhat the escape of the water molecules. If the air molecules could somehow be swept away, the water molecules would leave the liquid much more readily. This can be seen if we inclose the vessel containing the water to be boiled and draw the air out with a suction pump. When this is done, the water boils with extreme readiness. As a vacuum is approached in the space above the water, the boiling temperature may drop as low as 100° or less, instead of the normal 212°. In fact, we should not forget that the boiling temperature of water is 212° only when the air pressure is normal; that is, about fifteen pounds per square inch. That is why one can hardly cook food at the top of a very tall mountain. The air pressure at such heights is so low that water boils too easily. The temperature of the water is then too low to harden an egg or to soften meat.

Let us return to the water molecules that escape from a pot of boiling water. If the pot is not tightly covered, the water molecules shoot out among the air molecules, spread into the room, and eventually into the whole outdoors. But if the lid is screwed down tight upon the pot, as in a pressure cooker, the water molecules soon crowd into the space above the liquid. As boiling continues, available space becomes less. Soon the crowded air and water molecules exert



This diagram will show you how gaseous air is changed to liquid air. A certain amount of ordinary air is allowed to enter through the valve at 1, after which the valve is shut. The pump at 2 compresses the air, which then passes through the pipe (3) into a vessel (4). The vessel is constantly cooled by a circulation of cold water. Passing on through the inner pipe (5, 6), the air finally escapes rapidly through the fine opening at 7. Its rapid expansion cools the air still more. Now very cold, it must pass up and around the pipe (5, 6). As it moves through this pipe, the air is cooled still more. Finally the cold air travels through 8 to the entrance of the compressor pump at 1. All this happens over and over again. Eventually, when the air reaches a temperature of about −220 F., it changes to a liquid and collects in the reservoir at 9. The liquid air is drawn off through the valve at 9. Surrounding the reservoir and the pipes it contains is a heat insulator (10) which is usually of the vacuum-bottle type.

a back pressure upon the surface of the liquid. It becomes more and more difficult for additional molecules to escape from the liquid. This back pressure soon causes boiling to stop. But heat energy is constantly being added by the flame. What happens? If the vessel is strong enough to withstand the strain, and it usually is so in a pressure cooker, the boiling temperature goes up. Instead of boiling at 212°, the water boils at 250° or 300°, and so on. Such high temperatures are of course very useful for cooking quickly foods that are tough and fibrous.

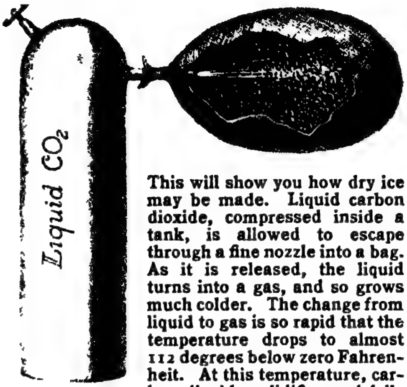
How Boiling Temperatures Vary

Other liquids behave as does water, except that their boiling temperatures at normal air pressure vary. Mercury requires a higher temperature to change its state and alcohol a lower temperature. The most easily boiled liquid is ether. You may be interested in trying the following experiment. Moisten a sponge in water and swab the sponge on the back of the hand. Note the sensation as the water evaporates. Repeat the experiment with alcohol, and then with ether. The ether dries most quickly and the water requires the longest time to evaporate. The evaporating ether causes the hand to feel colder than does the alcohol; and the drying alcohol cools the hand more than does the water. Evidently the heat energy needed to change the liquid into a gas is absorbed from the hand. The faster the rate of evaporation the more rapid is the absorption of heat energy.

How We Manufacture Liquids

In general, the molecules in a liquid are closer together than they are in a gas. It might seem, therefore, that if we forcibly pressed together the molecules of a gas, the gas would change to a liquid. This has been attempted many times, with powerful compressing pumps, but with no success. One can crowd together all the air molecules in a room until they occupy no more space than is in a thimble, without producing a

liquid form of air. But if we subtract enough heat from this thimbleful of compressed air, it changes into a clear waterlike liquid. This process of compression with cooling has been applied to many gases; so that we can manufacture not only liquid air, but liquid oxygen, liquid nitrogen, liquid chlorine, liquid hydrogen, and even liquid helium. Helium is the most difficult of all gases to change to a liquid.



This will show you how dry ice may be made. Liquid carbon dioxide, compressed inside a tank, is allowed to escape through a fine nozzle into a bag. As it is released, the liquid turns into a gas, and so grows much colder. The change from liquid to gas is so rapid that the temperature drops to almost 112 degrees below zero Fahrenheit. At this temperature, carbon dioxide solidifies and falls as snow. The carbon dioxide snowflakes are then gathered and compressed into blocks.

It is strange to think of air as a liquid. Stranger still are the effects which liquid air produces upon objects which it touches. So much heat energy is subtracted from air before it liquefies, that it is extremely cold. In order to appreciate the effects which liquid air produces, let us see just how cold it is. We all have some idea how cold ice is. Since the temperature of ice is 32°, and that of boiling water is 212°, we can say that normally ice is 180 Fahrenheit degrees colder than boiling water. Now, liquid air is about 346 Fahrenheit degrees colder than ice. A kettle of liquid air finds ice so hot, in comparison, that the air boils when placed on the ice. A rubber ball immersed in liquid air becomes as hard and brittle as glass. The soft petals of a rose, after a bath in liquid air, crumble into dust. Liquid mercury is frozen solid by liquefied air, so that one may use the lump of mercury to drive a nail into wood. Soft and juicy grapes turn into hard, stonelike pellets. Tin becomes brittle and lead elastic.

Who would ever have thought that a cake of ice could be warm enough to make anything boil? Yet that is what is happening here. The kettle contains liquid air, which is rapidly boiling away as it receives heat from the ice. It is all to be explained by the fact that air, or any other gas, will turn to a liquid only when it is extremely cold -- very much colder than ice. So when the liquid air is set on a cake of ice, it receives enough heat to turn it back to a gas again that is, to make it boil.

There are scientists who believe that some day in the very distant future, our earth will grow so cold that its atmosphere will condense into liquid air. By that time, the oceans of water will long since have become solid ice; and upon this hard surface, the rain of liquid air will fall, forming rivers and lakes of liquid air. Under such conditions no kind of life, we know life to-day, could exist.

Whether or not such a future awaits our earth, it is surely true that only the energy possessed by the molecules of air stands between us and that future. If that energy were somehow taken away from the air molecules, our gaseous atmosphere would change to a liquid.

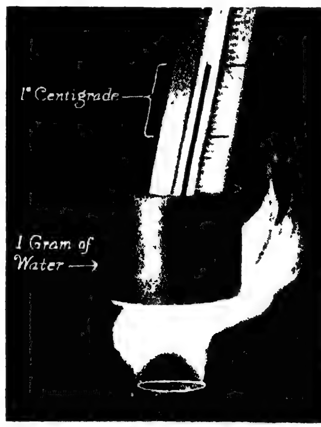
Some gases change readily into liquids under certain conditions. When they do, they give up a considerable amount of heat energy. Such a gas is steam. You can convince yourself of this by placing your finger in a jet of steam pouring out of a boiling teakettle. Note that there is about a half-inch space just outside the spout -- and before the cloud begins -- where nothing can be seen. The cloud is only warm to the finger, but the invisible area, where the real "live" steam is, is scalding hot. This is explained by the fact that the steam, in condensing, gives up a large amount of heat. It is only in that little half inch that we have real steam. The white cloud contains merely water vapor—like any other cloud.

We make use of the heat release during condensation, in the steam-heating systems of buildings. Live steam rising from the boiler in the cellar condenses inside the

metal radiators. In doing so, it releases heat energy, which makes the radiators hot. Thus the heat of the furnace changes a liquid into a gas, and the gas gives back this heat when it changes back into a liquid.

Mixed with the molecules of air are always many molecules of water. We refer to this water as atmospheric moisture and we can measure the amount of such moisture in terms of relative humidity. Now, this moisture exists in a gaseous state; and so, if heat energy is somehow subtracted from it, liquid water may form. Thus, a sudden lowering of temperature causes droplets of moisture to form in the air. Then we have a cloud or fog. Often these droplets cohere and become too heavy to stay aloft. Then we have rain. If it is cold enough, the gaseous water may change at once into a solid form. Then we have snow. When falling raindrops freeze, we get sleet or hail.

For ages man has watched the heat of the sun change solid ice into liquid water, but the discovery that heat can also liquefy many other solids is comparatively recent. Perhaps this was because stones seemed to be unaffected in the heat of a fire and because wood burned rather than melted. At any rate, it is not so long ago in the history of mankind that some curious huntsman built a fire around a strange kind of stone and watched with amazement as a red-hot liquid began to flow out from the flames. To him the discovery meant a new and better spear head. For us this early beginning has led to the varied use of metals, so vital in modern civilization.



In the vessel above is one gram of water—about a thimbleful. In raising the temperature of this water one degree Centigrade, the flame must add one "calorie" of heat energy. If there were a pound of water in the vessel and the rise in temperature were one degree Fahrenheit, the flame would add one British Thermal Unit (B.T.U.) of heat energy.

The Importance of Melting Solids

During the two or three thousand years which separate us from that ancient huntsman, many experimenters have sought to increase our knowledge of solids that melt when heat is added. In the so-called Bronze Age a mixture of melted metals, copper and tin, played a great part in the life of men. To-day the chemist is devising new ways of melting metals and of mixing them in different proportions so as to meet new needs and create new products. There is hardly an article made of metal which has not first been melted during the process of manufacture. We must melt metal in making automobiles, building structures, bridges, trains, ships, machines of every description, clocks, safes, pins, knives, razors, telephones, radios, batteries, jewelry, musical instruments, and thousands of other things.

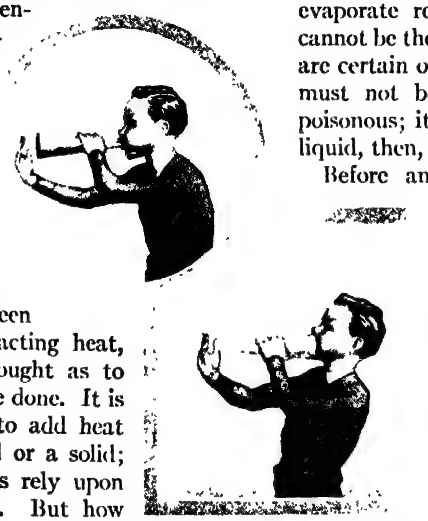
Nor must we forget the importance of melting snow and ice. Absorbing heat energy from the sun, the snow on mountain tops melts and flows down in streams to provide water for drinking, for irrigation, for transportation, and for power. Sometimes the flood is too great, and then it may do great damage. The spring floods which visit the Mississippi Valley are such a menace to life and property that our government is spending much money to control the flow of melted snow and ice.

The same amount of heat energy which is added to a piece of ice in order to melt it must be taken out of the resulting liquid in order to freeze it. Scientists measure heat energy in a unit called the "calorie" (kăl′ô-rĭ). Thus it requires 80 calories to melt one gram of ice into water. If this water is to be changed into ice again, 80 calories must somehow be taken out of the water.

There are many examples of the solidification of liquids in the world about us. In each case, freezing results in a release of heat energy by the liquid that freezes; which is another way of saying that heat must be subtracted from a liquid if it is to change to

a solid. We have already mentioned the fact that mercury can be frozen by cooling it in liquid air. We have also discussed briefly the many modern products arising from new ways of melting and mixing metals that are then permitted to solidify. The formation of snow, sleet, and hail are also important examples of solidification. Here, the release of heat energy to the atmosphere is so noticeable that we often remark, "How much warmer it is, now that it has begun to snow!"

Up to this point, we have been adding and subtracting heat, without much thought as to just how it may be done. It is relatively simple to add heat energy to a liquid or a solid; for we can always rely upon the sun or a fire. But how does one take heat away from a liquid or a solid? We cannot always depend upon the weather; for it often gets warmer instead of colder. Then how shall we keep food cold in summer? How can we cool the air in our homes, offices, and theaters? How can we cool foods and preserve them from rapid decay? These questions have been answered by the modern system of refrigeration. Let us try to understand how this system operates.



Here is a way to blow hot and a way to blow cold. When the boy blows into the narrow end of his trumpet, the lung-warmed air simply comes out warm. When he blows equally warm air into the wide end, the air is somewhat compressed, after which it escapes in a rapid stream through the narrow end. This rapid expansion cools the air. The narrower the opening, the cooler the stream of air.

The Basis of Refrigeration

From the experiment of swabbing one's hand with water, we have seen that the hand is left cold as the liquid evaporates. Heat must be added to the liquid before it can change to a gas; and this heat comes from the hand. From the point of view of the liquid, heat energy is gained; from the point of view of the hand, heat energy is lost. If alcohol is used, the rate of evaporation is faster; hence the loss of heat by the hand is greater. With ether the rate of evaporation is fastest, and so the hand feels coldest. This is the basic idea employed in all refrigerating systems.

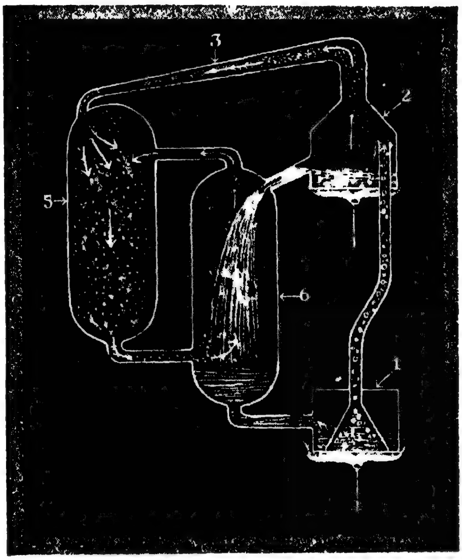
Obviously, if we are to find a way of making objects cold, we must find a good "refrigerant"; that is, a liquid that will evaporate readily. Yet rapid evaporation cannot be the sole reason for selection. There are certain other considerations. The liquid must not be too costly; it must not be poisonous; it must not be explosive. What liquid, then, is best of all?

Before answering this question, let us consider another fact. When a liquid evaporates, its molecules escape from a crowded condition into a space where they are freer to move. If we start with a substance that is normally in the gaseous form, and compress it by means of a pump, the molecules exert great pressure in trying to escape from their confinement. If we allow a very small hole through which they might leave, they rush out furiously. In doing so, they absorb heat energy from their surroundings, just as do the molecules of an evaporating liquid.

If one desires convincing evidence that this heat absorption really takes place, let him hold his hand in the escaping air from an automobile tire. The rapid exit of air molecules into less crowded conditions results in a cooling effect just as great, and perhaps greater, than the cooling that follows the spreading of liquid alcohol over the hand.

Thus the problem of finding a suitable refrigerant becomes one of selecting the most desirable gas to be compressed. Many have been tried. Ammonia, carbon dioxide, sulphur dioxide, ethyl chloride (ĕth'ĭl klō'-rīd), a recently manufactured gas called di-fluoro-dichloro-methane (dī-flōō'ō-rō-dī-klō'-rō-mĕth'ān), and even steam have been and are employed. Each has its advantages and some disadvantages.

Dry ice, or "carbice," as the chemist calls it, is a product that is finding new uses every day. It is colder than ordinary ice, for its temperature is lower by about 102 Fahrenheit degrees. It does not weigh so much, and does not melt. Instead, dry ice changes directly from solid to gas.



This diagram will show you how a gas refrigerator works. The reservoir at 1 contains ammonia water. When the lower gas flame is burning, the ammonia water rises through the tube to the "generator" (2), just as water rises in a coffee percolator; for the water inside the inverted funnel grows hotter than the water around the funnel and, expanding, is forced to mount upward by the colder water that pushes in at the bottom. The upper gas flame drives off the ammonia gas, which passes into the "condenser" (3). The cold air around the condenser rapidly brings down the temperature of the gas. Then the cooled gas, now condensed to a liquid, passes into the "evaporator" (5), which contains hydrogen gas. In the evaporator the ammonia expands rapidly, especially since its expansion in hydrogen is greater than it would be in air. Now the rapid expansion of any gas greatly lowers its temperature. It is the chilling of the gas in the evaporator, therefore, which lowers the temperature of the whole refrigerator and freezes the water in the ice-cube trays. The mixture of hydrogen and ammonia gases sinks to the bottom of the evaporator and flows into the "absorber" (6). Pouring into the absorber is an overflow of water from 2. The water absorbs the ammonia that has come from the evaporator, but it does not absorb the hydrogen, which is free to rise and flow into 5 again. The ammonia water settles down into The entire process continues so long as the gas is burning.

The essential steps in the manufacture of dry ice are as follows: First, carbon dioxide gas is highly compressed in a strong metal cylinder, which is cooled on the outside by a stream of cold water. Inside the cylinder the molecules are so crowded together that one may assume the gas to have turned into a liquid form. Second, a spray nozzle leading from the tank is opened to let the gas rush out into an inclosed chamber. This quick expansion results in heat absorption so rapid that the gas itself is greatly cooled. It is cooled sufficiently to form solid crystals which fall to the bottom of the chamber as carbon dioxide "snow." Third, the "snow" is gathered and compressed into blocks of so-called "dry ice."

Even before the day of the small automatic home refrigerator, more than ninety per cent of the ice used was made artificially. Very little of it was natural ice, cut from frozen rivers and lakes, and stored for use during the summer months.

Now an ice-making plant uses a rapidly evaporating refrigerant in a very simple way, though the machinery for doing so may seem rather complicated. The whole process has been described in our story of refrigeration.

Not only theaters, but office buildings, department stores, trains, and homes are now being supplied with artificial refrigeration. Scientists and engineers refer to this development as "air-conditioning," since the air is given both a desirable temperature and a desirable humidity. The methods employed are very similar to those described in the preceding section; although the refrigerant is usually different. Ethyl chloride and sulphur dioxide are perhaps the most frequently used refrigerants; and the substance with the strange name quoted before is becoming increasingly popular. On trains, steam from the locomotive exhaust is used as the refrigerant. It is allowed to expand rapidly into an empty chamber.

In the description of the way in which an ice-making plant operates, we mentioned a cold-storage room where the air is kept cool by the brine pipes. Let us assume that this room is a large one and that a powerful fan can sweep its conditioned air into ducts or channels leading to the theater or to the rooms of a house or office building. We should then have, in effect, the scheme employed by air-conditioning machinery.

In an electric refrigerator, seen in many a home and described on other pages of these books, the refrigerant is usually what we call Freon-12 gas. An electric motor drives a pump that compresses the refrigerant into an air-cooled tank. Then rapid expansion or evaporation takes place in a coil of pipes surrounding the ice-cube trays. Not only does the coil freeze the water in the trays, but it cools the air in the vicinity. The cold air falls, and a convection current is set up which bathes all the food in the stream of cold air. The electric switch which controls the motor is adjusted so that it automatically starts the motor when the circulating air gets too warm. It also stops the motor when the air cools to the desired temperature. The switch is set to operate at about 40° Fahrenheit, and it depends for its automatic action upon a strip of metal known as a compound bar. We have already explained, in a previous story, how the expansion of such a bar, due to heating, may be used to operate switches and valves.

How Water Is Frozen by a Gas Flame

Then there are gas refrigerators. Many people are quite mystified by this method of making things cold. How is it possible to freeze water by means of a hot gas flame? The mystery disappears when we examine the operation step by step. In order to do this, we shall need the help of a diagram.

In the first place, study the diagram carefully and familiarize yourself with all the parts. Learn where the "flame" is, the "percolator," the "condenser," the "evaporator," and the "absorber." Then, with pencil in hand, point to the part under discussion as you read the explanation.

The refrigerant is a water solution of ammonia gas, and it is kept under some pressure in the percolator. The flame operates to transfer some of the refrigerant to the generator. There the heat of the flame, which reaches to the generator as well as the percolator, drives off the ammonia gas into the condenser. Cold air that circulates around the condenser reduces its temperature and causes the ammonia gas to condense. Escaping through a narrow opening into the evaporator, the ammonia gas absorbs heat from its surroundings. In order to make the evaporation more rapid, the absorber contains hydrogen gas instead of air. This rapid evaporation results, of course, in a cooling effect. Thus, the absorber becomes the cooling element which freezes the water in the ice-cube trays and starts the convection current of cold air around its path through the food compartments.

What Becomes of the Gases

Now the mixture of ammonia and hydrogen gases drops downward and passes into the absorber. There water overflowing from the generator drips down through the absorber and dissolves the ammonia gas again; but not the hydrogen. The latter is thus permitted to rise—it is a light gas—and to pass again into the evaporator. The newly formed water solution of ammonia gas finds its way into the percolator once more, and the process continues so long as the flame is lighted.

Here, too, a compound bar acts as an automatic switch to shut off the gas when the temperature is low enough. The shut-off valve, however, is never permitted to act so as to shut off the gas completely. There remains always a small pilot light which ignites the greater flow of gas as it is needed.

The Advantages of Modern Refrigeration

The modern refrigerator is a great improvement over the unsanitary use of a cake of ice in an ice box. In the older method, food is placed near or against a substance which has been dragged in dirt, handled by many unclean hands, and hauled up a dumbwaiter that also carries the garbage can. The new type of automatic ice box is clean, efficient, and convenient. It never runs out of ice. It always keeps food at a uniform temperature, too low to permit decay. It provides ice at less cost than the older and cruder method.

Living conditions and health in general are being improved by modern methods of refrigeration.

PHYSICS

Reading Unit No. 17

WHAT A RAY OF LIGHT CAN DO

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is the speed of light? 1–413

How was the Chicago World's Fair opened? 1 413-14

The electric eye, 1 414

Light, a form of energy, 1–414-15

Radio and light waves, 1–418-19

Ultra-violet rays, 1–419

Infra-red rays, 1–419

Color and wave length, 1–419

Things to Think About

How was the speed of light first determined?

What is the difference in wave length between radio and light waves?

What is meant by the wave length, or frequency, of broadcasting station?

Why may we some day call the twentieth century the "Age of the Photo-electric Cell"?

Picture Hunt

How may a distant star start a motor? 1-414

How may a fire be detected with an electric eye? 1–415

Related Material

How does light form the colors of the grottoes of Capri? 1–87

How does light affect plants? 1 87, 2-46, 223

How is light energy stored for use on the earth? 1–343-46, 9–435

How is the photo-electric cell used in sending photographs through electric wires? 10–94

How does the photo-electric cell make talking movies possible? 10–504

How does television depend on the photo-electric cell? 10–124-25

How is light controlled by lenses? 1–427, 430-34

Leisure-time Activities

PROJECT NO. 1: With the aid of several friends, demonstrate the wave theory of light, 1 416.

PROJECT NO. 2: By means of graphs, show your friends what 860 kilocycles and other broadcasting frequencies mean, 1–418-19.

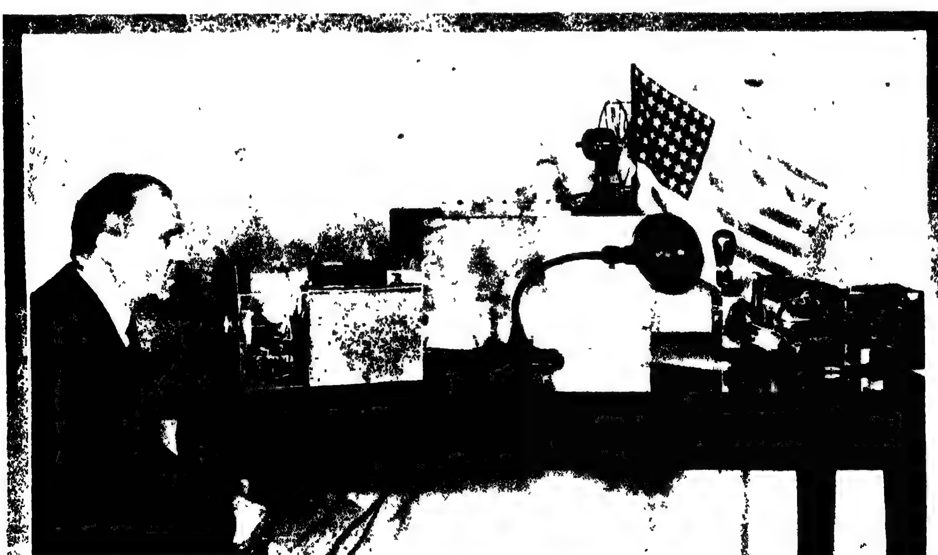
Summary Statement

Scientists are still investigating the nature of light energy, and are undecided as to whether it is a series of wave motions, a stream of particles, or both But though they still have much to find out about it, they have learned to control this form of energy for many useful purposes.

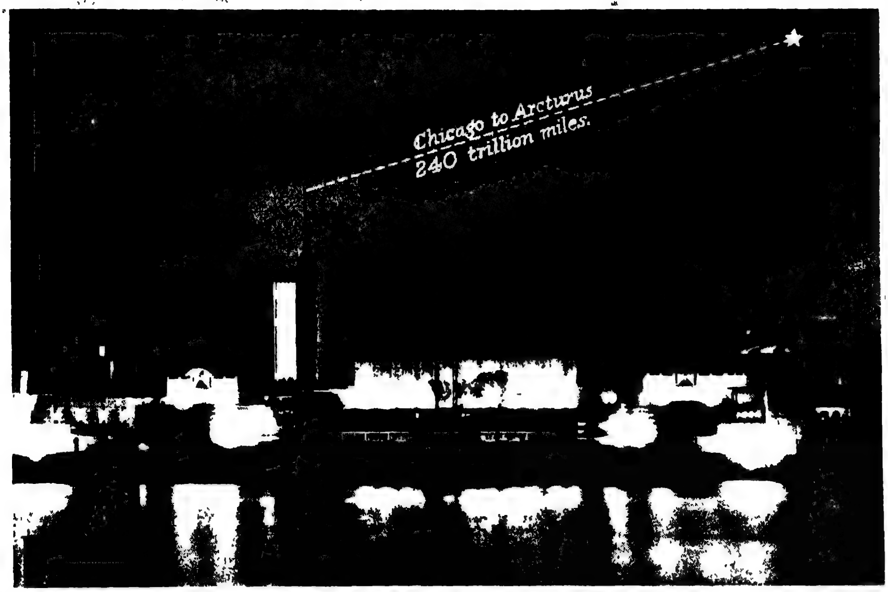
WHAT A RAY OF LIGHT CAN DO

Photos by Westinghouse Electric Co.

This is a modern version of the William Tell story. The actors are a research engineer and Rastus, the mechanical man. The experimenter takes aim with his bow and arrow, but instead of releasing the arrow, he presses a button. A ray of light flashes from the arrow, the apple is knocked off Rastus' head, and Rastus sinks back with a very human cry of relief. It is all very mysterious until you know how it is done. When the experimenter pressed the button, he shot a ray from a photocell flashlight, hidden in the arrow, at an object near the apple. The object was a photo-electric cell which, being sensitive to the light ray, released a mechanism that brought about the wonders described above. Rastus' cry of relief came from a phonograph which was set going by the photo-electric cell. And it was all started by pushing a button!



Witch doctors and medicine men would be very glad to know how to bring about some of the uncanny effects which the experimenter is producing in the picture above. He has only to talk into a telephone transmitter to start a very complicated mechanism going. The vibrations set in motion by his voice operate a series of relays, shutters, and other devices. These allow a light beam to strike a photo-electric cell. This cell, shown to the right in our picture, causes an electric current to operate other relays. These, in turn, control various colored lights, electric fans that make the flag flutter in the breeze, and other devices.



A ray of light from the star Arcturus must travel for forty years before it reaches us; that is why Arcturus was chosen to be the star whose rays should open Chicago's Century of Progress Exposition. The rays of light that launched the spectacular lighting display at the opening of the World's Fair of 1933, had left Arcturus forty years before—when the Chicago World's Fair closed in 1893.

WHAT *a* RAY *of* LIGHT CAN DO

How a Ray That Started to the Earth Forty Years Ago Can Open a World's Fair for Us Now

IF YOU had been getting ready for more than three years for a certain event and had spent millions of dollars to make it worth while, you might wish to usher in the occasion with a little ceremony. Perhaps you would ask the President of the United States to make a speech and throw a switch that would start proceedings. If the event were important to the people, the President would probably not hesitate to do so.

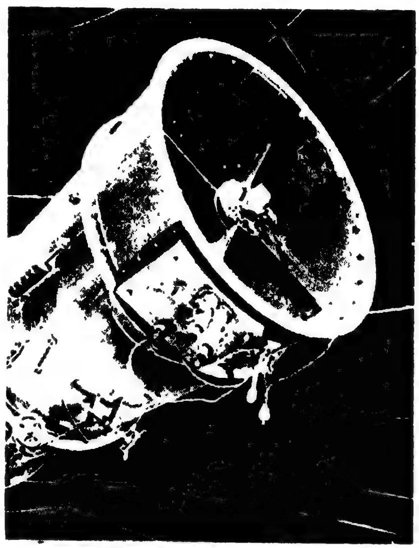
But the city of Chicago did not open its great World's Fair of 1933 by asking the President to push a button. There was, of course, no intention of slighting him; rather was it the wish of those in charge to select a more appropriate method for opening a scientific celebration. The World's Fair of 1933 was called the Century of Progress Exposition. During the preceding hundred years the world had seen no greater progress than that in the field of science.

The fair was opened in a most unusual manner. To understand it, one must go back in his mind to the year 1893 and transport himself out into space for a distance of 240 trillion miles. At this vast distance from the earth in the direction of the constellation known as Boötes, we find the bright star Arcturus. In 1893, a beam of light started from this star toward the earth. It started at the moment when the Chicago World Fair's of 1893 closed. For forty years this beam of light traveled through space, covering distance at the rate of about 186,000 miles each second. In forty years there are many more than a billion seconds. On it traveled, with un-

diminished speed and without change in direction.

Finally, after forty years, in the summer of 1933 it reached the earth. Its path carried it to a telescope mounted on the fairgrounds. Entering this instrument, it fell upon a device known as a photo-electric cell. And the cell responded immediately by throwing a switch which turned on millions of lamps. The World's Fair of 1933 was opened in a blaze of light! A bit of light energy sent out from a distant star was thus honored, by being permitted to usher in the celebration of a century of scientific progress.

The world of the twentieth century is a very different place from any that has been known before. A vast number of the differences in it are the results of the growth of science. In one field of knowledge this growth stands out very markedly: in the field which has to do with energy that travels through space.



Here is a motor run by light rays from distant stars. It took Dr. Coblentz fifteen years to build. The motor is so sensitive to light that it can measure accurately the energy coming to it from stars that are hundreds of millions of miles away. In one instance this motor responded to a quantity of energy so small that it would have had to be directed steadily at sixty drops of water for a hundred years in order to raise the temperature of the water one degree.

The sun and the stars shine upon us now as they have shone for countless thousands of years; but we now understand a little better just what is involved in their shining. This better understanding has led to the "shine" which comes from a radio station or from a television broadcast. It has helped us to control such things as electric waves, heat waves, ultra-violet waves and X rays. Further study of the kind of energy which travels through space has given us the marvelous "electric eye"—a photo-electric cell—which has been put to use in so many ways. Electric eyes count for us; they stand guard tirelessly and give warning when a fire breaks out; they open and close doors for us whenever we wish them to do so and when we find it inconvenient to do it for ourselves; they sort out packages and help to control street traffic; they start ventilators in tunnels when poisonous gases accumulate in too great quantity; and they make the "talkies" possible. There seems to be no limit to the service which electric eyes can render. It almost seems as if the twentieth century might some day be called the "Age of the Photo-electric Cell," just as other periods in history have been called "The Stone Age" and "The Bronze Age."

Because light energy is so remarkable in the things it can do for man, and because its real nature is still so mysterious, the scientific celebration at Chicago in 1933 was appropriately opened by a bit of light energy from the star Arcturus. In this way the attention of the world was called to the importance of light and to the advances in civilization which our better understanding of it has made possible.

Now what is light? A simple answer would be, "Light is a form of energy." But what is energy? To this, the only reply possible is that energy is the ability to do work. Hence, light becomes one kind of ability to do work. Clearly, the answer is rather vague and not very helpful to anyone who wishes a mental picture of what a beam of light is. Just what was it that came from Arcturus to open the World's Fair? Something did come. In fact, it took forty years to get here, after traversing 240 trillions of miles of space.

Photos by Westinghouse Electric Co

To the left is Dr. Thomas with his mechanical fire-watchman. The device on the table is constantly swinging up and down and to the right and left. It has inside it a photo-electric cell which scans the entire screen over and over again. When this "electric eye" spots one of the flaming wads of cotton which the experimenter has placed on the screen, it stops and turns on a fire extinguisher—all because the photo-electric cell is affected by the flame. When the fire is out, the device begins again its endless search for more fires. The inventor is shown to the right talking into a microphone. As he talks, the vibrations of his voice produce tiny electric currents that flow into the box at the left. There they cause a streak of light to change to a wave form. Every variation of his voice, every different sound he utters, shows itself by a wave of different shape in the circle on the box which stands to the left.

Unfortunate as it may be, scientists have never been able to get an entirely satisfactory mental picture of what a beam of light is like. The best they can do is to propose imaginary pictures and then see how well the facts about light fit the picture they propose. Perhaps this is disappointing to us; but we should bear in mind that even an imaginary picture—the scientist calls it a "theory" (thē′ō-rĭ)—has its uses. It is quite remarkable that when a scientist proposes a theory to explain facts which he observes, the theory soon leads him to new facts. These may cause him to change his theory; whereupon he is put on the track of even more interesting facts. The process continues until his picture becomes better and more complete in detail. Never does he arrive at an *absolutely* complete picture; but he is constantly learning more about the world in which he lives. This is happening in the field of electricity, in the field of chemical action, in the field of living plants and animals, in the field of the stars, and also in the field of light energy.

So instead of trying to give a direct answer to the question, "What is light?" let us consider some of the pictures which have been proposed by men of science to explain the facts we can observe about light.

Sir Isaac Newton believed that light energy behaves as if it were a stream of particles. Accordingly, sunshine is a bombardment from space of numerous tiny pellets. Unable to say what these pellets are, and being in no position to gather up a number of them for further examination, Newton was compelled to say that the pellets were weightless. In a sense, this was an admission that light particles do not really exist. Still, the theory was very useful in some ways; for it helped to explain such matters as the reflection of light, the formation of shadows, and light absorption. The theory was therefore accepted, in spite of the fact that it asks one to believe in pellets that have no weight. Not until about 1800 was the theory discarded in favor of a better one.

Huygens' Theory of Light

As a matter of fact, the Dutch scientist Huygens (hī′gĕnz) explained his own very different theory of light several years before Newton made his announcement. But Newton's reputation was so great that the ideas of Huygens did not become popular for a hundred years. In the end they proved to be so much more helpful and reasonable that all scientists accepted them. Only very recently have some doubts arisen; but even

to-day we must rely upon Huygens' theory to explain certain facts about light. It is therefore necessary to learn something about what Huygens had in mind.

Let us begin by asking the reader to perform an experiment. Get six or seven pieces of rope, each about twenty feet long. Give one end of each rope to a different person and ask each of your six or seven friends to tie the rope securely around a finger. Hold the six or seven remaining ends yourself. Arrange the group so that you are in the center and your friends around you, with the ropes fairly taut. In this experi- e in the center represents a source of light energy, and those around represent places in space where the energy is received. Although in this experiment we have only six or seven such places, we may imagine dozens, hundreds, even millions of additional places, each connected with the source by a rope.

Now, the energy source suddenly gives an up-and-down jerk to all the rope ends which he holds. This jerk raises a hump in each rope, like the crest of a wave. The hump quickly travels out from the center of disturbance to each of the hands holding the other ends. Arriving at a hand, the hump causes that hand to jerk. If there were a million hands holding rope ends, each one would feel the original jerk. Evidently, a bit of energy is thus transmitted from one point in space to every other point that is connected with it by means of a rope. Note that the rope is very necessary. There must be something to transmit the energy. After all, it is a hump which, moving along the rope, finally reaches the receiving point. If there were so many ropes tied to the center that they filled all space in every direction, the energy in the jerk would be received everywhere in space.

Huygens believed that a source of light is a center of disturbance, that the energy of this disturbance goes out in all directions, and that it may be received at very distant points. But he held that *something* must connect each receiving point with the center of disturbance, just as in our experiment with the ropes. Hence he assumed that all space is filled with a substance which he chose

Dr. Thomas is operating the "stroboglow." In his hand is a neon lamp which glows for only three ten-millionths of a second, but the operator can regulate the number of flashes appearing per second. When the fan is started, the blades move so rapidly that one cannot distinguish the letters painted on them. However, when Dr. Thomas causes the flashes to occur at the same rate as the rotation of the fan, the blades seem to stand still and the letters may be read easily. With this device, one can examine carefully and minutely what is happening to an object that is revolving 30,000 times in a minute.

The boy in the middle, below, is the source of energy. As he jerks his end of the ropes, the jerk travels in the form of a wave to each of the boys around him. This rope experiment, as it is explained in our story, will help you to understand one of the theories of scientists concerning the nature of light and the way in which waves travel through the ether of space.

Photos by Westinghouse Electric Co

to call the ether (ē′thēr). It is the ether which transmits the energy from the center of disturbance; that is, from the source of light. Just as a hump resembling the crest of a wave carries energy along a rope, so waves in the ether carry light energy from the source out into space.

From our experiment with the ropes we may recall that the hump raised by the jerk travels rather quickly through the rope. Yet it takes a little time for the energy to traverse a distance of twenty feet. Light energy traveling through the ether also takes a certain amount of time. To be sure, the speed of travel is very fast. Indeed, it was believed . . the beginning that light takes no time at all in going from one point to another.

If an airplane could circle the globe at the same speed as light travels, the plane would complete seven trips around the earth in one second.

How Galileo Experimented with Light

Galileo once tried to measure the speed of light by placing an observer on each of two mountain tops. The distance between observers was carefully measured. Each was given a lamp which he could cover up or expose at will. The first observer flashed his light and began to count seconds. When the second observer saw the flash, he immediately flashed his own light. When this was seen by the first observer, the latter stopped counting and noted the amount of time that had elapsed. In this way Galileo had hoped to determine how long it took light to travel to and fro across the known distance. But the experiment failed utterly; the beam of light traveled the entire distance in less time than was used by the observer in covering or exposing the lamp. Galileo very wisely concluded that light moved too rapidly to be measured in this way.

In 1675 a scientist named Roemer (rû′mēr) managed to measure the speed of light by means of a series of observations of one of the moons of Jupiter. He finally found the speed to be about 186,000 miles a second. Since then other scientists have made even more elaborate measurements, and have found that Roemer was essentially correct. The American scientist, Albert A. Michelson, accurately measured the velocity of light in his mile-long tube on the outskirts of the California desert. He found that light traveled at a speed of 186,284 miles a second in a vacuum and a trifle more slowly in air. Experiments with radar impulses—which travel with the speed of light—as they are reflected from the surface of the moon, have verified Michelson's figure. The fastest airplane could fly to the sun in about eighteen years. Light energy from the sun, however, reaches us in about eight minutes.

Returning once again to our experiment with the rope, we recall that the jerk raises a hump in the rope. A second jerk causes another such hump. If the jerking continues, the entire rope begins to look like a snake. It reminds one of a series of waves. The number of wave crests which form depends upon many things; but chiefly upon how rapidly one jerks the end of the rope, how heavy the rope is and how taut it is pulled. With a little practice one can learn to throw the rope into short waves or long waves, just as one wishes. The length of the wave is measured from the top of one crest to the top of the next, or from the bottom of one trough to the bottom of the next.

The Helpful Theory of Ether Waves

Now according to Huygens' theory that the ether plays a part like that of the rope, we must think of the ether as being thrown into "waves." Of course such "waves" cannot be seen; but we can think of the ether as behaving in this manner. Since

the ether itself is an imaginary substance, it can do no harm to imagine that it assumes a wave form while transmitting light energy. Far from doing harm, this mental picture is very helpful; for it gives the scientist a chance to draw a wave curve on paper and to base calculations upon curves so drawn. From these calculations the scientist can actually measure the length of the ether wave when light is transmitted by the ether.

As a result we are told by scientists that the wave length of light energy may vary from about a forty-thousandth part of an inch to about a sixty-thousandth part of an inch. In other words, the waves of light are so small that in every inch of ether transmitting light energy there are from 40,000 to 60,000 crests.

This is James Clerk Maxwell, the great English mathematician and physicist. His mathematical equations enabled him to state that there must be such things as radio waves. Twenty years after his prediction, Hertz, the German scientist, was able to produce and receive radio waves.

Sometimes the scientist refers to wave motion in the ether in another way. He counts the number of crests which pass a given point in one second. This he calls the "frequency" of the light energy. In the case of light energy, the frequency may vary from about 400 trillion to about 700 trillion. Such numbers are almost unimaginably large; yet instruments have been devised which take measurements that seem to show these figures to be correct.

The Amazing Discovery of Radio

We can understand how anyone reading what has been said about imaginary ether, imaginary waves, and figures based upon imaginary waves, may be doubtful about the whole theory. We should indeed be more than doubtful but for the fact that the theory has led us, step by step, to some of the greatest achievements of modern science.

For instance, there is the radio. Snap a button and music fills the room—music that is being played hundreds of miles away. But the radio is a direct result of the scientist's mental picture of light energy as a wave motion in the ether. The radio might have come without the ether theory; but the fact is that it did come with it.

In 1864 James Clerk Maxwell, an English scientist, showed that it ought to be possible to produce an ether wave which would not be light at all, but something quite different. It would be different in only one respect; namely, that the wave length would be very much longer than the forty-thousandth of an inch which is the length of a light wave. Twenty-four years later, in 1888, the German scientist Hertz (hĕrts) found a way of producing such a wave. That was the beginning of radio broadcasting; for the ether wave which Maxwell predicted and Hertz produced was a radio wave! It was not long before Hertzian waves were being produced, varying in length from a mile or more from crest to crest to lengths of only an inch or so.

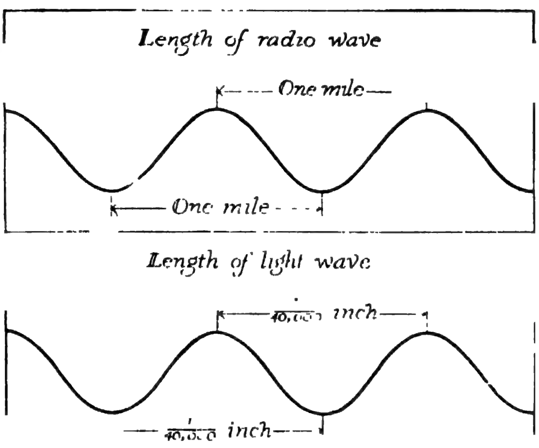
To-day we turn to our favorite radio station and set the dial for, let us say, "420 m." What does "420 m." mean? Simply that our favorite station is broadcasting on an ether wave that has a length of 420 meters. If the number happens to be "860 K.C.," then it is the frequency of the ether wave rather than its length which we are using. "860 K.C." means 860 kilocycles, or 860,000 cycles. In such an ether wave, 860,000 crests go by a given point in one second.

In a previous story we discussed at some length three ways in which heat energy may travel from one place to another. One of these ways was called "radiation." Heat from a fireplace comes to us by radiation, as does the heat from the sun.

Here, too, the theory of ether waves is very helpful; for it regards heat radiation as a series of waves in the ether. The only difference between heat waves and light waves is that heat waves have a greater wave length. The longest wave length for light is about a forty-thousandth part of an inch,

while a heat wave or radiation has a length that is nearer a thirty-thousandth of an inch.

It was quite natural that the discovery of waves greater in length than those of light should urge scientists to a search for waves shorter than those of light This search has also been successful. Waves only one-millionth part of an inch in length have been found. They are called "ultra-violet rays." Then the marvelous X rays were shown to be waves of a length so short that more than two billion crests can fit into the space of an inch. Even shorter waves have been found and called "gamma rays." Finally the mysterious cosmic rays were discovered; and although scientists are not entirely agreed as to whether these rays are really ether waves, many believe that they are, and that their wave length is even less than a trillionth of an inch.



Radio waves and light waves are very similar. The only difference is in the wave length. Radio waves are very much longer from crest to crest than light waves are, as you can see in the diagram above. They may be a mile or more long, whereas light waves are but 1/40,000 inch. But certain insects seem to have eyes which are sensitive to much shorter wave lengths. If this is so, the world they see must appear very different from our world, with colors in it that we cannot see at all.

One reason why man was slow to discover the very short and the very long wave lengths was that these waves do not affect his sense of sight or touch. Ether waves which vary in length from about one forty-thousandth of an inch to about one sixty-thousandth are received by the human eye as light. They make seeing possible There is not a very great difference in length between a forty-thousandth part of an inch and a sixty-thousandth part of an inch; yet the tiny variations possible between these limits account for all the colors of the rainbow. Red light corresponds to the longer of the limits and violet light to the shorter one. Orange, yellow, green, blue, and indigo are produced by wave lengths that become progressively shorter as one goes from the long to the short. If ether waves are a little greater in length than those of red light, they cannot be seen. They are called infra-red rays. It happens that most of the infra-red rays are felt as heat; but if they are longer than about one-hundredth of an inch they do not even affect the sense of touch. One is unaware of their existence. The radio receiving set, which *can* receive these longer waves, thus becomes an artificial sense that supplements the sense of sight and of touch.

In the same way, the waves just shorter than violet carrying ultra-violet rays--are invisible. Yet they are important, for they stimulate plants to grow and are necessary for human health. To catch the ultra-violet rays we make use of cameras and other similar instruments. Again, these instruments become artificial senses which supplement the meager equipment that nature has given us.

We ought to say that not all of these short wave lengths are helpful to mankind In fact, some of them are rather deadly. Scientists tell us that the earth's atmosphere absorbs the deadly waves which the sun sends out.

As for the extremely short waves, such as the X rays, gamma rays, and, perhaps, the cosmic rays, they are certainly not visible. Man has again had to devise instruments for detecting them. All of us are familiar with the remarkable photographs which X rays make possible. Gamma rays and cosmic rays are even more penetrating; and, as time goes on, important uses for them will surely be found.

In considering the wide variety of ether

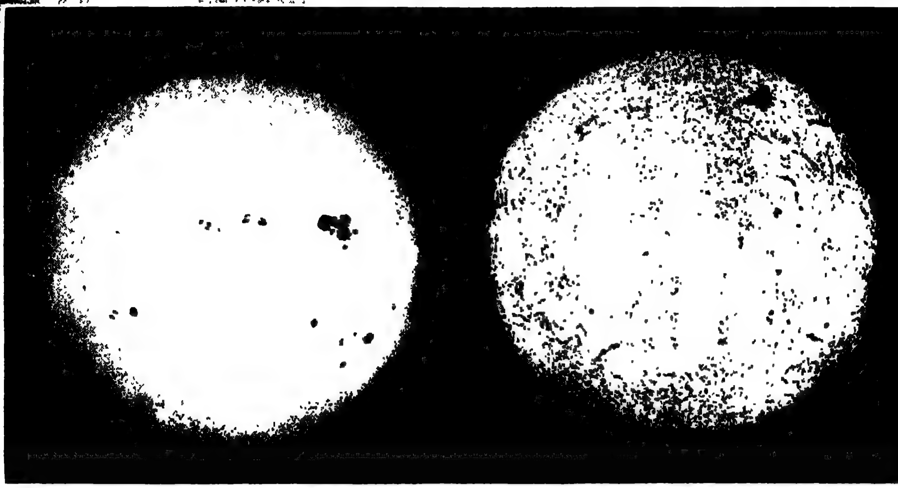


Photo by Mt. Wilson Observatory

Light rays are affected differently as they pass through different substances. At the right above you see the sun as it looks when photographed by the light of hydrogen. At the left is a direct photograph.

waves possible between radio waves—miles from crest to crest—and cosmic rays—trillionths of an inch in length—one is struck by the fact that human seeing and feeling are confined to only a very narrow range. Man may well be proud of having a mind that has found out how to use ether-transmitted energy which he cannot see, hear, feel, taste, or smell.

In the light of all these discoveries, can one continue to reject the mental picture which scientists have constructed of waves in the ether? We are somewhat in the position of a person trying to fit together a large picture puzzle. After shuffling and sorting the many different pieces, we decide that the picture is that of a man on horseback. The notion seems reasonable and we proceed to fit together one piece after another. Pretty soon two-thirds of the pieces are in place and bear out our notion that the picture *is* a man on horseback. Yet some of the pieces have not yet been placed. Indeed, a few are so odd that we see no way of using them. What shall we do? Shall we discard the notion of a man on horseback? We are free to do so. Perhaps a man on a bicycle would be a better theory. Yet no other theory seems to take care of so many pieces as the one adopted. And so we hold fast to this one, trying to modify the picture somewhat and hoping that every last piece will eventually find its proper place.

Thus it is with our theory of ether waves. It does not explain all the facts about light, but it accounts for most of them. Anyone who refuses to accept the theory has a right to do so; but such rejection carries with it a duty of explaining in some better way the behavior of light energy.

Recently, as a result of the work of men like Planck (plänk) and Einstein (īn′stīn), another and perhaps a better theory of light has seemed possible. This theory makes it unnecessary to assume that such a thing as the ether exists. Also, it looks upon light energy as a stream of tiny parcels, or "quanta," of energy called "photons" (fō′-tŏn). Yet the new theory is not entirely satisfactory. The solution of the whole problem lies in the future. In the meantime, we may make the most of the picture which shows light as waves of certain lengths in an imaginary substance called the ether.

PHYSICS

Reading Unit
No. 18

HOW LIGHT BEHAVES

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The path of a beam of light, 1–423, 427-28
Mirages, 1-424, 426
"The Specter of the Brocken," 1-425
The "Fata Morgana," 1–425
Freak mirrors, 1–426-27, 429
Transparent and opaque bodies, 1–427-28
Lenses, 1 432-33
Dark objects and light energy, 1 429-30

Things to Think About

Why do we seem to ourselves to be standing as far behind a mirror as we are actually standing in front of it?
Why are images inverted by convex lenses?
How were Einstein's calculatiors as to the position of a certain star proved to be correct?
How may ships be seen floating in the air?

Picture Hunt

How is it possible to see two airships in the sky when only one is actually there? 1–423
How may certain shadow effects in the water or in the air be explained? 1–425
How is light reflected? 1–428

Related Material

How does a camera focus images? 1–436
How do astronomers photograph the stars? 1–188, 190
How does the eye form images? 2–295-300, 1–436
How did Galileo's telescope affect the history of civilization? 13–96-97
How may distant objects be photographed in some detail? 10–452
How has the work of Leeuwenhoek revolutionized the health of the world? 10–487-90, 13–362
How is light transmitted by television? 10–125
How is the measure of distance, called a light year, used by astronomers? 1–172

Practical Applications

How are lenses used in cameras? 1–433-34
How are pictures projected on a screen? 1–434

Summary Statement

Light coming from an object and entering a human eye usually travels in a straight line; but air conditions, a mirror, or a lens may change this path to make it curved or broken. No matter by what path a ray of light enters the eye, the eye sees the path as a straight line.

From the looks of the freak in the mirror one would say that the rays of light from the man's head and neck strike the mirror where it curves one way while the rays from his body strike a different curve.

Here the mirror must curve in at least three different ways. The middle bulge in the image of the man is undoubtedly caused by a similar bulge across the center of the mirror.

Photos by Pittsburgh Plate Glass C

Our mirrors are getting worse and worse. Here we have one so distorted that two men side by side are reflected quite differently. One man is almost normal; the other is far from normal!

This absurd-looking man is looking into several curved mirrors at once—with the curves running smoothly into one another. So he appears to be three-headed, like the mythical Cerberus.

This is *not* a picture of two dirigibles. The airship at the right is merely the shadow of the other, cast by the setting sun on a bank of clouds or mist. Coupled with this phenomenon, one sometimes finds a series of faint circular rings or halos behind the shadow. The rings are caused by a spreading—the scientist calls it "diffraction"—of the light rays by tiny ice crystals in the mist.

HOW LIGHT BEHAVES

Every Ray of It Is a Pathway along Which Energy Is Rushing

N A previous story we tried to explain what the scientist thinks light is. Perhaps we did not succeed beyond making it clear that no one really knows what light is; that more than one mental picture may be made of light energy traveling through space. Be that as it may, we deal with an entirely different matter in now considering how light acts.

Even if we cannot give a complete description of the nature of light, we can tell how it behaves, or devise means for controlling it and making it serve our purposes. In other words, we know a great deal about what light does—how it is reflected, how it is bent, how it is scattered, what happens when it passes through lenses, and so on. These are the things we shall study now.

Let us begin by agreeing upon what we shall call a ray of light. Whatever light is, we know that it travels from one point in space to another. Hence there must be a path along which the energy travels. This path is the ray. Sometimes the path is straight, sometimes it is crooked or curved. It may be that the method of travel is by means of tiny waves in an imaginary ether; but that has nothing to do with the direction of travel. A ray is merely a direction. Although this direction tends always to be a straight line from point to point in space, there are many things, such as air, water, mirrors, and lenses, which can cause light energy to change its path. A bundle of rays traveling in more or less the same direction is called a *beam* of light.

Several boys were once engaged in a heated discussion. One claimed that cats can see in the dark. Another insisted that they cannot, if the place is really dark. The rest took sides on the question, helping along with facts and argument.

"Why," said one, "everyone knows that cats and owls see well enough at night to catch their prey. They see pretty sharply, too."

"Yes," was the reply, "but the night is never absolutely pitch-dark. A cat's eyes are more sensitive than human eyes. Cats and owls can do more by starlight than most

When rays of light pass at an angle from a more dense into a less dense transparent substance, their direction of travel is changed. The sands of the desert are hot during the day, and the air next the sand is hot and very much expanded. So some of the rays of light from a distant tree top must pass from cold dense air into warm air of lower density. Those rays are therefore bent, as shown by the curved line in the picture above. Now the eye of the observer receives not only these bent rays but also direct, straight ones. The straight rays cause one to see the tree in its normal position. The bent rays are seen by the eye as a straight line; so another, inverted image is seen. Thus the thirsty traveler seems to see palm trees reflected in a lake—for the image of the sky is inverted, too. This false appearance is known as a "mirage"; it may be met with whenever air is heated in such a way that it lies in layers of varying density. These layers are labeled a, b, c, and d in the picture. The straight rays pass above them.

humans can in sunshine. But shut up a cat and an owl in a dungeon without windows, and neither will see the other."

Can You See in the Dark?

"I doubt that very much. I can prove you are wrong. Did you ever go into a motion-picture theater and find yourself practically blind, so far as seeing a seat is concerned? Then, after the usher has guided you to your place and after your eyes have grown used to the darkness, didn't you find that you could see everything more plainly? That proves that eyes can get used to seeing, even in the dark. A cat is just a little better at it than a human being. That is all."

"There is one flaw in your reasoning. The motion-picture theater is not ·ompletely dark. There is light on the screen and there are many exit lights. If these lights were removed, you could remain there for a month without being able to see a finger in front of your nose."

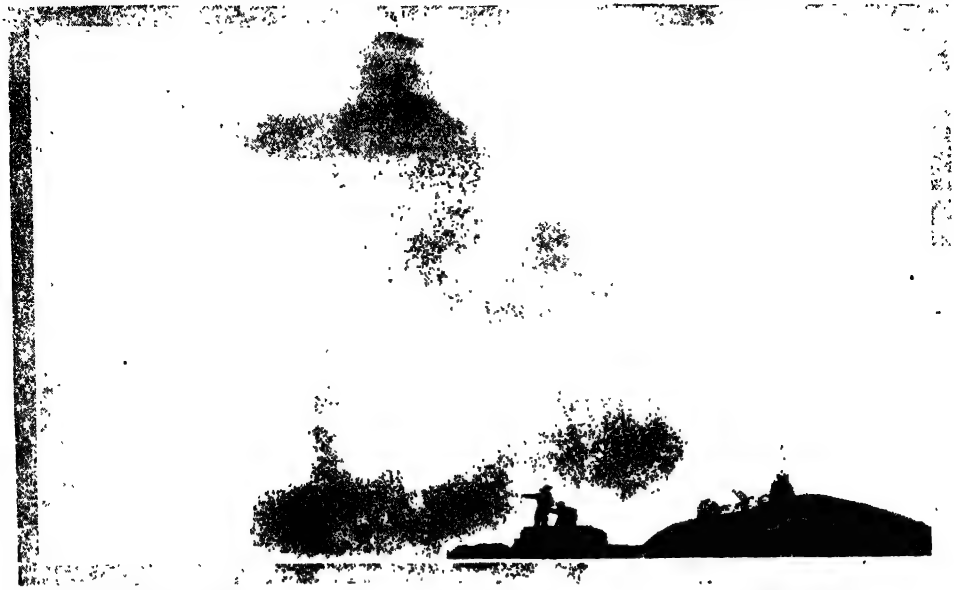
At this point, one of the group introduced this fact: "One can see in the dark if the objects are colored white. I can always see white curtains, no matter how dark it is in the room. It all depends upon the color."

"No, I cannot see what color has to do with it. If the room is totally dark, all objects have the same color; that is, they are all black and therefore invisible."

And so the discussion continued. Who was right? Perhaps the wise thing for the boys to do would have been to shut themselves up in a totally dark room and test their ideas. Had they done so, they would have discovered the truth about their own eyes, at any rate. They would have quickly found that they can see nothing in total darkness. As for cats and owls, there is no evidence that they can do better than we can in a pitch-dark room.

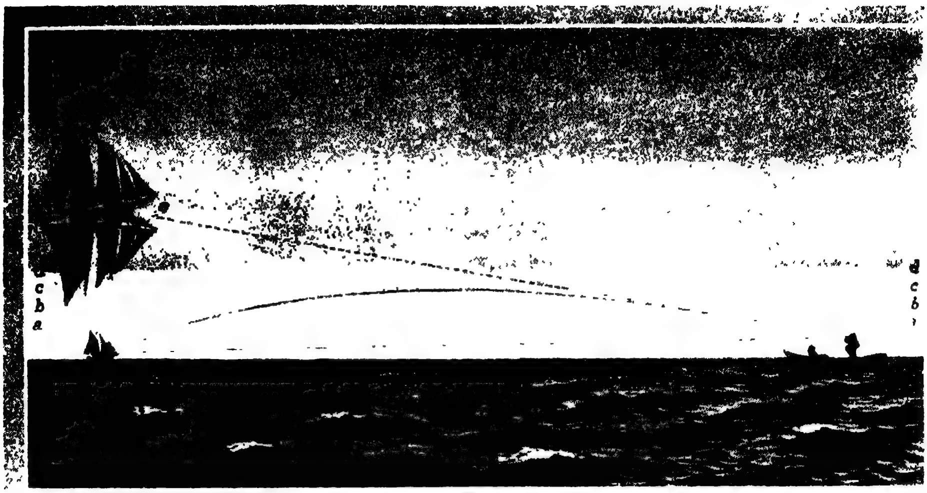
When an Object May Be Seen

We must accept the fact that we see an object only when light from that object enters our eyes. Sometimes, when we have been using our eyes in a bright light, we do not see objects that send us dim light. That is what happens when we enter a darkened



Germany's famous "Specter of the Brocken" must have struck terror to many a simple mind in the days when there were no scientists to explain its forbidding shapes. Standing on the summit of a tall mountain called the Brocken, with the sun setting at their backs, people see gigantic, grotesque shadows dimly resembling men. If the people move, these distorted shapes move, too. The bank of clouds in front of the people acts as a screen upon which the shadows are cast. This can happen only when the sun is low on the horizon and when the air is heavy with mist. Sometimes in misty weather, magnified images of ships will appear above the horizon before the ships actually appear in sight. This is called "looming."

In the Straits of Messina, between Sicily and Southern Italy, the Fata Morgana, a weird mirage, sometimes distorts the rocks on shore and changes their low hulks into lofty towers and pinnacles. Superstitious sailors believe strange things about this peculiar behavior of rays of light; but science explains it very nicely by showing that the light is refracted in peculiar but understandable ways by the diverse currents of air which are frequently to be found at that place. The Fata Morgana got its name from Morgan le Fay, a fairy who, in the legend of the Round Table, is King Arthur's treacherous and evil-doing sister. The lofty towers and pinnacles that appear in the shimmering waters of the Straits of Messina were said to be of her making. Some people said that they were the castle where the fairy dwelt.



The air close to the ocean sometimes lies in layers of different densities. In the picture above, the topmost layer, d, is less dense than the next layer, c; c is less dense than b, and so on. Rays of light from a distant ship will not only pass directly in a straight line to the eyes of the men adrift in the rowboat, but also in a curved line, for some of the rays will be bent by the layers of air of varying density. The result is that the men see another image high up in the air. Sometimes the image is magnified and so seems to be near at hand—for we usually associate large size with nearness. If the layer next the water is very dense, the men may not be able to see the direct image of the ship at all.

theater from the bright outdoors. After our eyes are rested a bit and the pupils have become enlarged to let in what light there is, we find our vision improved. It may happen, also, that one object sends us so much light that we do not see other objects near it because the light which they send out is so much less intense. Thus we do not see the stars in the daytime—not because they are not shining, but because the sun's light is so much stronger. Exclude the light of the sun by looking at a star through a long pipe and you may find that you can see the starlight even by day.

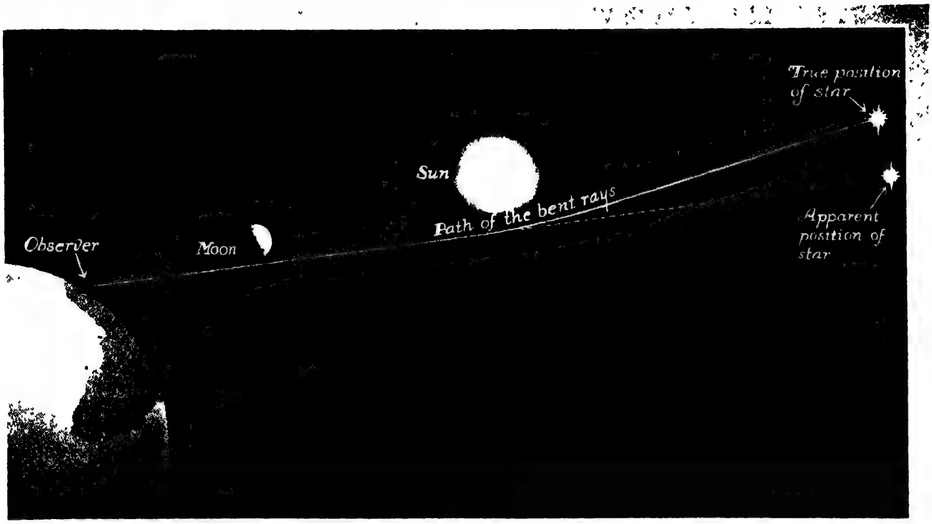
What Is a Mirage?

Desert travelers often report seeing strange sights. These are called mirages. For example, the traveler sees what looks exactly like water even where there is no water near. The light rays from the distant sky are refracted up from the desert sands; so the traveler sees the sky as in a mirror, and thinks it is shimmering water. The cause is the heating of the desert sands by the sunshine. Of course, there is also the possibility that the traveler is parched with thirst and that his mind is feverish. In that case, we are dealing with imagination rather than fact, with an hallucination rather than with the illusion created by a true mirage.

How the Path of Light Changes

Light coming from an object and entering a human eye usually travels in a straight line; but air conditions, a mirror, or a lens may change the path to a crooked or a broken one. No matter what kind of path the ray pursues, however, the eye sees the object at the end of a straight-line path. The direction of this path is the direction of the ray as it enters the eye.

It is so necessary to understand this that we ask the reader to study the picture we have shown by way of illustrating it. A boy sees a baseball. He sees it because light from the ball enters his eyes. But notice the path which the light pursues. First, a lens bends the ray, and then three mirrors reflect it before it reaches the eye. The path is therefore bent and broken. Yet the eye sees the ball at the end of a straight-line path whose total length is the same as the broken path, and in a direction which is the final one that the ray takes when it enters the eye. One should note that the boy



Einstein concluded from some of his studies that a beam of light is attracted by a large mass when the light passes quite close to the mass; he even predicted the amount of this pull. During a total eclipse of the sun, when the moon blots out the sun entirely, astronomers have a good opportunity to measure the positions of stars whose rays pass near the sun. In the picture above, you see where the star really is and where it seems to be. As its rays pass the sun they are bent to one side, but the eye doesn't know this and so the observer seems to see the star at the point indicated. Einstein's advance calculations and the astronomers' actual measurements agreed almost perfectly. This was one of the important proofs of Einstein's great theory of relativity, which has given scientists a new idea of the nature of matter.

sees the ball in a place where it really is not.

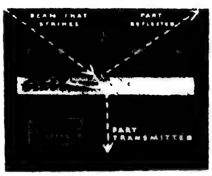
Seeing things where they are not, happens more often than we think, because the air, which is always between the things and our eyes, tends to make the path of rays crooked. Fortunately this crookedness is not very great, and so we see things in practically the places where they really are. It is otherwise, however, when we look at the sun. When a beam of light from the sun strikes the earth's atmosphere, the path is bent before reaching the eye. Since the eye sees the entire path as a straight line, the sun appears to be where it is not. In this connection, it is interesting to know that we see the sun rise before it is really above the horizon, and that we see it for some time after it has really sunk below the horizon.

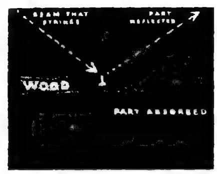
Study this picture to see if you can see what happens to the rays of light coming from the ball. The real ball is at the left. It sends out a ray of light that is first bent by a lens and then reflected by three mirrors before it enters the observer's eye. Since the observer thinks he always sees in a straight line, the entire broken path seems to be straightened out for him; this brings the apparent position of the ball to the point indicated at the right.

Looking down upon the surface of a lake, one sees an image of trees on the opposite shore or of the distant hills. The sky too is sometimes visible in the lake, which then takes on a blue color. If the wind is blowing so as to cause ripples in the water, these images are not seen clearly, if at all. The surface has to be smooth. Why is this so?

When a beam of light strikes a piece of matter, it may either go through or bound away. If it goes through, the matter is said to be transparent; if it does not, the object is opaque (ō-pāk'). Sometimes only some of the light energy goes through; then the object is said to be translucent (trăns-lū'sĕnt). In that case the rest of the light

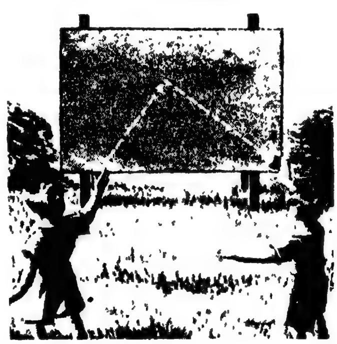
is either absorbed or thrown off. Usually some is absorbed and some is reflected—that is, thrown off. As a matter of fact, no substance is perfectly transparent. Therefore a beam of light passing through air, water, or glass, divides into three parts. Part is reflected from the surface, part is absorbed, and part is permitted to go through. A beam striking an opaque substance divides into two parts, that which is reflected from the surface and that which is absorbed. The amount reflected, the amount absorbed, and the amount transmitted depend, in all cases, upon the kind of object which the light strikes and the angle at which it strikes.





This shows the difference between glass, a transparent substance, and wood, an opaque substance, when a beam of light strikes each at an angle. When the beam strikes glass, it is divided into two portions; one is reflected, and the other is transmitted but bent twice—once upon entering the glass and again upon leaving. In the case of wood, part of the beam is reflected, but the rest is absorbed.

Let us consider the light that is reflected. In which direction is such light thrown off? The answer will be suggested if one watches a rubber ball being bounced on the floor. If the ball strikes perpendicularly, it returns exactly in the direction in which it was thrown; but if it hits the floor at an angle, the ball rebounds at an angle. When these angles are measured, it is found that the "angle of strike" is exactly equal to the "angle of rebound." Now a ray of light energy behaves in the same way. Here, too, the "angle of strike" equals the "angle of rebound." In the words of the scientist, the angle of incidence equals the angle of reflection.



The reflection of a beam of light fro surface may be compared to the bouncing of a ball off a board. The angle at which the first boy throws the ball is the same as the angle at which it rebounds into the hand of the second boy.

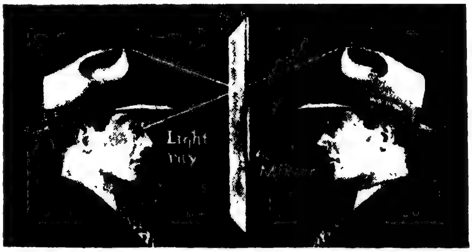
Here is another fact of importance. In the case of a bouncing ball, the floor must be smooth. Otherwise there is no telling where the ball will rebound after being thrown. Similarly there is no telling where or how a beam of light will rebound if the surface is rough. That is why one can see no clear image in a lake whose waters are rippled at the surface. The beam of light from the trees or the distant hills rebounds from the surface of the lake in many different directions. Very little of the beam is reflected directly to the eye. And so one does not see the reflected image.

Glass mirrors are excellent reflectors of light. Images seen in mirrors are clear, true, and almost as good as the objects themselves. On the other hand, it is impossible to see an image by reflection from a sheet of paper, for the smoothest paper is not so smooth as glass, especially if the glass is silvered. A light beam striking a sheet of paper is scattered in all directions. The rays from any object, after striking the paper, do not keep together. Although many of these rays do reach the eye, they are all mixed up, belonging to many objects at once. Hence no clear image is formed. In speaking of the light reflected from paper, from a smooth wall, or from other surfaces of the same kind, the scientist uses the term "diffused light." Every object one sees sends diffused light to the eye. Otherwise objects would be invisible. In order to see objects in a mirror, however, the light must be reflected as a beam.

Most of us have been puzzled at some time in our lives by the fact that as we walk toward a mirror our image seems to approach us. Stand in front of a mirror and look at your hat. Since you see it, a ray of light must come from it to your eye. How does it get there? Clearly, a ray from the hat travels to the mirror at an angle and re-

bounds at an equal angle to your eye. The ray's path is therefore a broken one; but the eye, as we have learned, sees this path as a complete straight line. Straightening out the path, brings the hat to a point somewhere back of the mirror. At that point you see the hat. This is but another example of seeing objects where they are not.

If you now walk a step nearer the mirror, you shorten the path of the ray from hat to mirror. This also shortens the path from mirror to eye. This new path, extending back of the mirror, is not so long. Hence the hat appears to be nearer to the mirror. This happens continually as you move toward the mirror, and explains why your image comes toward you.



A man looks at himself in a mirror. The ray of light from the top of his hat strikes the mirror and is reflected to his eye; but the eye sees the entire ray from hat to eye as a straight line. So the top of the hat seems to be at a point at the end of the dotted line. The same thing is true of every other part of the hat, face, and neck; so the man sees an exact image of himself in the mirror. Note also that the image is as far behind the mirror as the man is in front of it.

Procure a sheet of pliable and polished tin and look at yourself in it. It probably serves as a good mirror. Now, slowly bring the vertical edges toward each other, so as to bend the sheet into a curved semi-cylinder, with the hollow side toward you. Note what that does to your image. You become as thin as a toothpick. Release the edges, and you begin to look more like yourself. Now, bring together the top and bottom edges of the sheet. Does that make you look short and fat? You may amuse yourself, also, by looking into the curved mirror when its hollow side is away from you, rather than toward you.

How Curved Mirrors Reflect Light

What is the explanation of the funny images which curved mirrors produce? If one is to see a true image in a mirror, every part of one's body as seen in the mirror must be in its proper place with respect to every other part. It will not do to have one eye ten inches from the other if the real distance between them is but three inches. But if the mirror is curved, different parts of it present different angles to the rays which come from the face. Thus the "angle of strike" is different for different parts of the face. Since the "angle of strike" always equals the "angle of rebound," the latter will also be different for different parts of the face. The result is that the images seen of different parts of the face are in the wrong positions with respect to one another. The face then looks distorted and funny.

Curved mirrors are useful in many ways. By placing them properly around a lamp, a single shaft of light may be thrown forward. This is done in each of the two headlights of an automobile. In a sense, lamp shades and reflectors are curved mirrors. They help to confine the rays of light to a given area. Searchlights direct their powerful beams by means of curved mirrors; and one important type of telescope depends entirely upon a curved mirror in gathering as much starlight as possible. Whenever curved mirrors are used in the ways described above, the hollow or concave side of the mirror always faces the source of light. The convex side of a mirror spreads rather than concentrates a beam of light.

In a darkened room the objects that stand out are those that are light in color. When our eyes have become accustomed to the darkness, they may see clearly such things as white curtains or a bed sheet, while they do not see a dark rug or a black chair, except by contrast with objects that are lighter in color. This is due to the fact that white reflects light while black absorbs light. We are all familiar with the way in which light-colored walls brighten up a room. Dark walls are an expensive luxury, since they require much more electricity for lighting. Classrooms are darker than they would be without the strip of blackboard around the walls.

What happens to the light energy which dark-colored objects absorb? If light is energy, we know that it cannot disappear. If the energy is not reflected, then it must remain in the object; but in another form. This new form is heat. The molecules of a dark object begin to move faster as light energy falls upon them. Perhaps we can now see a good reason for wearing light-colored clothing when the weather is hot. Also it should be clear why dirty snow melts faster than clean snow. Finally, we can now see why a burning glass focused on a pure white piece of paper does not set fire to the paper so readily as when a pencil smudge is first prepared upon which the light rays may focus.

When a beam of light strikes a lens, the rays are bent to a point, called the "focus." Upon that point a good deal of light energy is concentrated. If a ray of light is focused in this way upon a piece of paper, the paper will absorb the energy in the form of heat and may finally begin to burn. Many a hiker has started a camp fire in this way, without the use of matches.

First place a coin at the bottom of a dish, so that the side of the dish hides the coin from view. Then pour water into the dish. Soon the coin will appear, in spite of the fact that your eye had not changed from its first position. To understand this, you must read our story which tells how rays of light are "refracted" when they pass from water into air.

Let us now try an experiment or two. Lay a coin at the bottom of a pot. Shut one eye and lower the open one until the side of the pot just hides the coin from view. Holding this position, let someone else pour water slowly into the vessel. When an inch or two of water covers the bottom, the coin becomes visible. How can that be, if your eye has not moved?

Why the Coin Can Be Seen

If you see the coin, then a ray of light must travel from coin to eye. This ray must evidently go first through water and then through air. The path cannot be in a straight line, since a straight line would be blocked by the side of the pot, which is opaque. The path, therefore, is not straight, but broken. A ray can start from the coin, bend as it goes from water into air and then travel toward the eye of the observer. This explanation proves to be the correct one. It helps us to understand why the water apparently raises the coin into view. Since the eye sees in a straight line, the broken path is straightened out in line with the ray that enters the eye. The coin is seen at the end of this straightened path. Clearly, the end of the path, where the coin is, must be raised. Thus we again see an object in a place where it really is not.

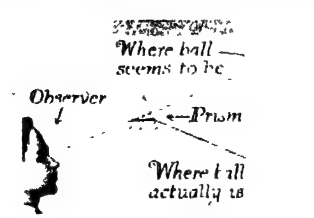
The bending of rays of light as they pass from one transparent substance into another is called "refraction." There are many examples of refraction in the world about us. Perhaps you have noticed how a teaspoon in a glass of water seems broken at the surface. The same is true of an oar in water or of your arm as it is partly immersed in the bathtub. Trying to reach for a cake of soap lying at the bottom of the tub is something of a problem, since the soap is not where it seems to be. In fact, the whole bottom of the tub seems abnormally raised; the water when it is viewed obliquely seems shallower than it actually is. The only simple way of gauging the actual position of an object under water is to view it perpendicularly. In the instances just cited, rays of light bend as they pass from water into air or from air into water.

In the previous paragraph we learned that a ray changes its direction in passing obliquely—or at an angle—from air into water or from water into air. Let us now follow the path of a ray as it goes from air into glass and out again. For this purpose a glass prism is helpful. To those who do not know what a prism (prĭz'm) is, we may say that it is any part of a piece of glass where two plane surfaces meet. Thus, the corner of a plate glass is a prism; so are the glass crystals which dangle from some

A stick partly immersed in a bowl of water looks bent at the surface. Your arm, partly submerged in the bath tub, will seem bent, too. This is because rays of light are refracted as they pass from water into air. In the same way refraction explains why we never see the sun where it really is, especially at sunrise and sunset. The line C, above, shows the actual path of a ray traveling to the observer's eye; it is bent by the layers of air surrounding the earth. The line A shows the path along which the eye seems to see the sun. Line B is the line of vision level with the horizon. All this explains why we can still see the sun for a few seconds after it has really set, and also why we can see it before it has risen.

chandeliers. A prism as used by scientists is usually a five-sided bar of glass in which the two ends are parallel and the remaining three sides at an angle to one another.

If one looks at an object through a prism held so that the rays strike one of the parallel ends, there will be very little difference from looking through an ordinary glass window. But if one tries to see an object by looking at it through one of the corners, the object cannot be readily found. In fact, one must hunt for it quite carefully; and when it is found, it seems to be at a point where it certainly is not. That is shown in our illustration. Note where the ball is, and the eye. Follow the path of the ray from ball to eye. The ray bends twice, once upon entering the glass and again upon leaving it. Of course the eye sees the entire broken path as a straight line; and so the ball appears to be where it is not. From this picture we see that a glass prism bends rays of light toward what is known as its base.

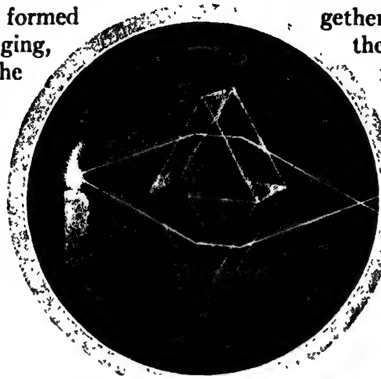


The diagram above will help you understand the picture at the top of this page. The ray of light from the ball to the eye is bent by the glass prism; but the eye sees it as a straight line. So the ball seems to be at quite a different point from the one where it actually is. The prism acts much as the earth's atmosphere does in refracting the rays of the setting sun.

We are used to thinking of lenses as rounded pieces of glass, such as the kind we find at the end of a flashlight or in spectacles. Sometimes the rounded surfaces bulge outward, so that the middle is thicker than the edges. In other types of lenses the bulge is inward, and the middle is therefore thinner than the edges. Scientists call the first kind convex (kŏn-vĕks′), or "outward-bulging," and the second kind concave (kŏn-kāv′), or "inward-bulging."

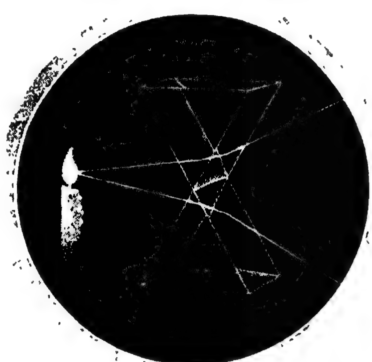
So many wonderful things are accomplished with lenses that we ought to know how they affect the paths of light beams which strike them. Let us begin, then, by pointing out that a lens is made up of many prisms. That is illustrated by the pictures we show on the next page. In the first, two prisms are placed base to base. Imagine the figure as broken up into a greater and greater number of smaller prisms, until something

very like a rounded lens is formed—a lens of the outward-bulging, or convex, variety. In the next picture the prisms are placed corner to corner. A great many small ones would produce an inward-bulging, or concave, lens.

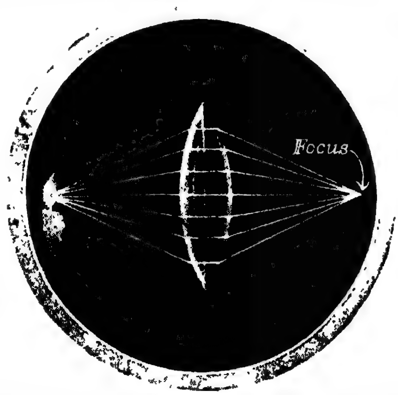


Rays of light from the candle flame above are bent by the glass prisms in such a way that the light is brought to a focus.

If two prisms are placed base to base, the upper one bends rays downward and the lower one bends them upward. This is exactly what the different parts of a convex lens do, since such a lens may be considered to be made up of two prisms placed base to base. Rays starting from a candle flame and falling upon the surface of a convex lens are, of course, bent by the lens. But how? That depends upon where they strike on the lens. A ray which reaches a point at the top of the outer rim of the lens, is bent downward. Another which strikes a point at the bottom is bent upward. Rays which strike at opposite sides are bent toward each other. The ray through the middle is not bent at all. If all these rays start from the same point on a candle flame, they meet at one point after passing through the lens. A well constructed lens will cause the millions of rays from any one point in the flame to come together at one point. This point is called the "focus" (fō'kŭs).



The prisms above are placed, not base to base, but point to point. Since the bending is always toward the base, these prisms cause the light rays to diverge—that is, to spread out.



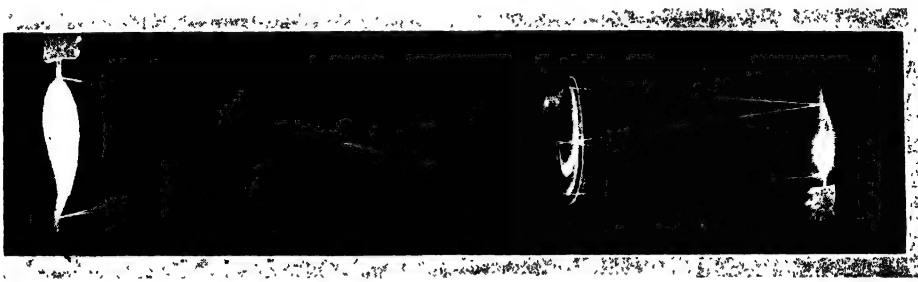
A convex lens, such as is shown above, may be considered as made up of prisms placed base to base; so such a lens brings rays to a focus. Similarly, a concave lens may be considered as made up of prisms placed point to point. Such a lens would cause rays of light to diverge.

Light from the sun travels in a beam of parallel rays. If such a beam strikes a convex lens, the rays are again brought together at one point. In this case, the point is called the "principal focus." The distance between the principal focus and the center of the lens is referred to as the "focal distance" of the lens. A so-called reading glass or burning glass is a convex lens. When held in the path of the sun's rays, it can bring a sunbeam to focus at a point on a sheet of paper. The resulting concentration of light and heat may set fire to the paper.

Some lenses focus sunlight at a point very close to the lens itself. These short-focus lenses have great curvature; that is, they are very outward-bulging. The long-focus lens is much flatter; its middle is not so thick in comparison with the outer edge.

Since a concave lens may be considered as made up of two prisms placed corner to corner, the bending of rays takes place in another manner. Consider three rays coming from one point in a candle flame and striking a concave lens. The one through the middle passes through without bending, the one which strikes near the upper edge bends upward, and the one striking near the lower edge bends downward. The result is that a concave lens spreads out a beam of light. It does not bring the beam to a focus. In speaking of the focus of a concave lens, we mean the point from which the spreading beam

When an object, such as a candle flame, is placed at a point more than twice the focal distance from a convex lens—that is, more than twice the distance between the lens and its focusing point—the image formed on a screen is inverted and smaller than the object. If you will follow the white lines in the diagram above you will see why this is. The cut shows how a convex lens is used in a camera.



When an object is placed at a point less than twice the focal distance but more than once the focal distance from a convex lens, the image formed on a screen is inverted and larger than the object. The diagram above shows how a convex lens is used in a lantern-slide projector or a motion picture projector. In this diagram, too, if you will follow the white lines you can understand what happens.

seems to spread. The focal distance is measured from this point.

Light a small candle and stand it on the table. At a point on the table about three feet away place a large sheet of cardboard. Our picture will help you to carry out this experiment. If the room is darkened, you will see that the candle flame sends out a beam of light which spreads out over the cardboard screen. The screen diffuses, or scatters, the light which it receives. Bear in mind the fact that each tiny point of the flame is sending out rays to every point on the screen. Hence, no clear image of the candle can be seen on the screen.

How the Candle Appears on the Screen

Now, hold a reading glass—a convex lens—between the candle and the screen and nearer to the screen than to the candle. Move the lens back and forth a bit until a sharply focused image of the flame is obtained on the screen. Note that the candle appears inverted—or upside down—and that it is much smaller than the candle itself. If the screen were a photographic film, the light of the image would affect the chemicals in such a way that the film could then be developed and printed to produce a picture of the candle flame. Thus we see how a convex lens is used in a camera.

By looking at our picture of this experiment you can see how the lens focuses the beam of light sent out from each point on the candle flame. Moving the lens back and forth helps you to find a position where all the focus points fall on the screen. In this way, it is possible for the screen to send to your eye a set of concentrated beams of light, rather than one grand diffused beam; and the screen, instead of being generally illuminated over its entire area, shows a distinctly outlined image of the object which sends out the light. The size of the image formed with any one lens depends upon how far away the candle is from the screen. This explains how a large "close-up" picture may be taken with a camera. The further away

one goes with the camera, the smaller will be the picture.

In the experiment just described, you were told to place the lens nearer to the screen than to the flame. Repeat the experiment holding the lens closer to the flame. Again an image may be focused; but this time, it is inverted and larger. The explanation given before holds in this case, too. If, instead of the candle, a glass slide or a "movie" film is used, the screen shows an enlarged image of the slide or film. The size of the image obtained with any lens again depends upon the distance between object and screen. A careful study of the illustrations for this experiment and the one described in the previous paragraph will show why the images are always inverted. Note that a beam of light issuing from the top of the candle flame crosses a beam coming from the bottom of the flame. Hence, by the time the beams focus on the screen, an image of the top of the flame is at the bottom and the one from the bottom is at the top.

We must point out that the lens should not be brought too close to the candle. If this is done, no image at all can be formed on the screen. The limit may be determined beforehand by measuring the focal distance of the lens used. Thus, a lens with a 10-inch focal distance should not be brought closer than 10 inches to the candle. Why is this so, and what happens if one does get too close to the object?

It is rather hard to tell in words just how the beams of light from each point in the flame are bent by a lens held close. The point is that the beams spread out after passage through the lens. They cannot focus on the screen and produce an image. But if these out-spreading beams are received by the eye, the candle flame is seen through the lens. The interesting fact about this image is that it is much enlarged.

When people use a convex lens as a magnifying glass, they place it close to the object to be magnified. How close do they bring the lens? That depends upon the focal distance. Placing the object anywhere between principal focus and the lens itself results in a magnified image. The greatest magnification is obtained when the object is just within the focus. This use of a convex lens is the basis of all microscopes. In the very expensive and complicated instrument called the compound microscope, the use of a convex lens is combined with that of other lenses, in order to obtain still greater magnification.

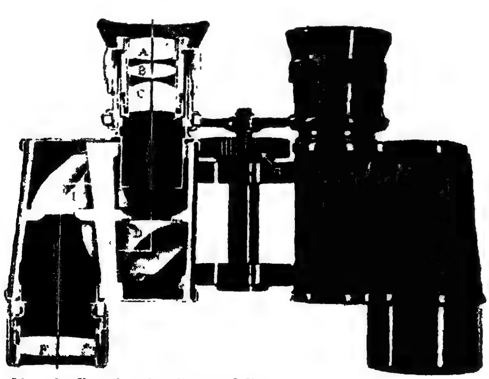
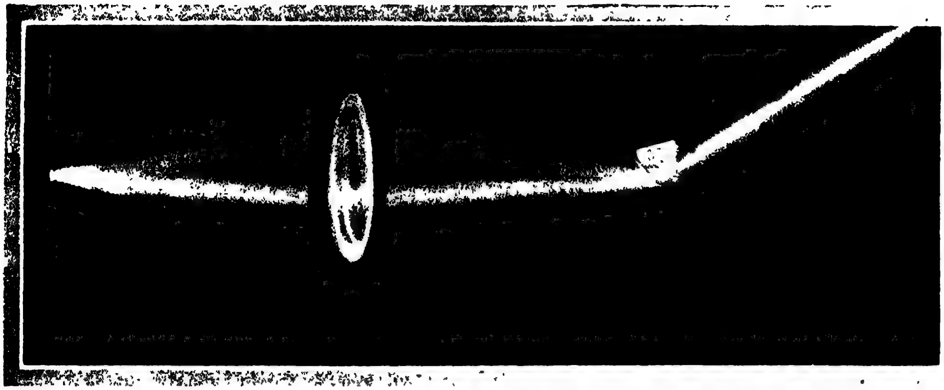


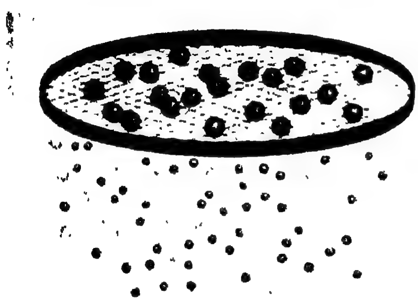
Photo by Bausch & Lomb Optical Co.

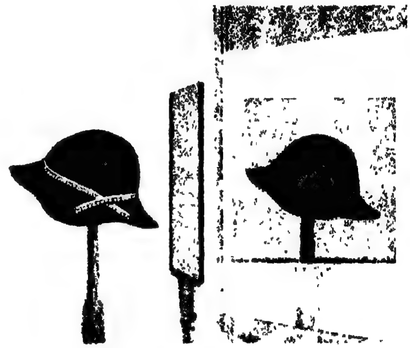
In any fine binoculars the rays of light from a distant object are brought to your eyes by an arrangement of prisms and lenses that is very complicated indeed. In the pair above, the eye is held to A, but the ray entering the eye has first passed through F and then followed the complicated path indicated by the white line. In glasses of this type the focus is adjusted for each eye separately. G regulates the distance between the eyepieces.

THE HUMAN EYE AND THE SECRET OF COLOR

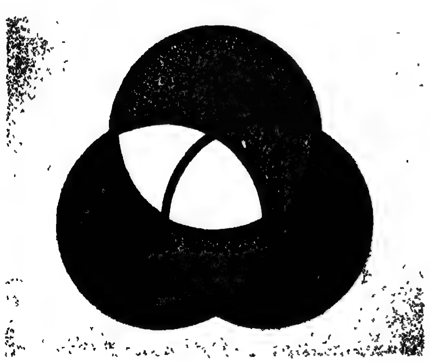


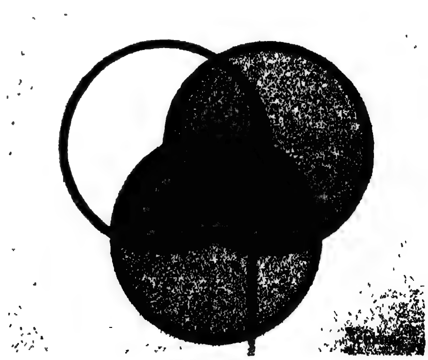
One of the most amazing things in all physics is the fact that the white light coming from the sun is made up of violet, blue, green, yellow, orange, and red rays. The picture above shows how a white ray is split into these colors when it is passed through a prism the wedge-shaped piece of glass shown at the right. A lens, properly placed, can then gather the rays together again into a white ray.





When white light falls on a red object, all the colors in the white ray are absorbed except the red rays, which are reflected to the eye. It is much like what would happen if marbles of all colors were put in a sieve of a size to hold only the red ones. At the right above, blue glass, which absorbs red rays, is placed between a red hat and a mirror. The hat in the mirror is black!





All the colors we see can be produced by combining three primary colors; in light, these are red, green, and violet-blue. Red and green rays make yellow; green and violet-blue make blue-green; violet-blue and red make purple. All three colors make white.

In mixing pigments—such as paint—the three primary colors which produce the rest are blue-green, purple, and yellow. Purple and blue-green make violet-blue, purple and yellow make red; blue-green and yellow make green. All three colors make black.

PHYSICS

Reading Unit No. 19

WHEN A RAY OF LIGHT FALLS ON YOUR EYE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The camera, 1–436
The eye, 1–436-37
Nearsightedness and farsightedness, 1–437-38
Astigmatism, 1–438
Mixing colors, 1–439-41
The spectroscope, 1–440
Camouflage, 1–440
Why snow is white, 1–439-40

Things to Think About

How can white light be separated into colors?
How can light of many colors be combined to form white light?
How do convex and concave lenses correct defects in the eye?
Why can we say that the camera is like the eye? How is it different?

Picture Hunt

What are the parts of a camera? 1–436
What are the parts of the eye? 1–436

Related Material

How is the eye protected? 2–347
How does the eye see color? 2–298
What gives the eye its color? 1–437
How may photographs be sent by wire? 10–94-99
Are photography and painting rivals? 11–330
How are trick photographs produced? 10–447, 449
How are pictures printed in newspapers and in magazines? 10–67-81
How does the eye make motion pictures possible? 1–437

Practical Applications

How do oculists correct vision? 1–437-38
How does a camera take pictures? 1–436

Leisure-time Activities

PROJECT NO. 1: Examine and learn the use of each part of your camera, 1–436.

PROJECT NO. 2: Make a color wheel, 1–439.

Summary Statement

The human eye has many structures similar to the parts of the camera. The lens of the eye is like the lens of the camera; the retina of the eye is like the photographic film in the camera; and the iris is like the diaphragm in the camera. But the lifeless camera lacks many of the delicate adjustments of the eye.

Photo by H. Armstrong Roberts

Each important part of the eye corresponds to an important part of a camera. The lens of the eye is like the lens of the camera; the retina of the eye is like the photographic film; and the iris is like the diaphragm in the camera. Of course the camera, being a lifeless, mechanical device, lacks many of the delicate adjustments that an eye possesses.

WHEN *a* RAY *of* LIGHT FALLS *on* YOUR EYE

Suppose You Saw a Red Dress in a Blue Light, What Color Would It Be?

THERE is a story about a group of blind people who lived hidden away from the rest of the world on a secluded and unknown mountain. Here they managed to pass a happy life, carrying on from day to day in a manner strange enough to us but satisfactory to them. Into their midst there wandered a man who could see. What a task he had to tell these people what he meant by seeing—by such words as light and color! Having no eyes, they could not have the faintest notion of a color or of light

If our eyes show us the light that shines over the earth and clothes it in so many colors, we may well talk a while about those two precious windows in our heads.

Most of us have used a camera for taking pictures. If so, we are probably familiar with its parts. First in importance is the lens—a convex lens that serves to focus the image of an object on a screen. The screen or film is the second necessary item in a camera. Usually it is a piece of celluloid coated with gelatin containing a chemical that is sensitive to light energy. The film and lens are inclosed in a light-tight box, part of which is a bellows that allows the lens to move back and forth for focusing. Then there is a diaphragm which controls the lens opening. Finally, there is a shutter mechanism which lets us open the lens for as short a time as a single hundredth of a second or for as much longer as we may wish.

The human eye has many structures similar to those of the camera. The eye also has a convex lens. It is not made of glass, but of a transparent fluid contained in a thin but tough sac. Here, too, the purpose of the lens is to focus an image on the screen, but the screen is not a chemically coated piece of celluloid. It is a network of nerve fibers, called the retina (rĕt'ĭ-nȧ), which connect through a main nerve channel with the brain. The socket containing the lens and the retina plays the part of the light-tight box in a camera. There is, of course, no extending bellows; for focusing is accomplished in another way. We do not move the lens in and out of its socket. Instead, we have certain muscles to change the curvature of the lens. This allows us to focus it.

The eye also has a diaphragm controlling the lens opening. It is called the iris, and it consists of a ring of colored muscle. When the ring contracts, we say the pupil is nar-

rowed; when the ring expands, we say the pupil is distended. Incidentally, it is the iris which gives the eye its color. The purpose of the iris is the same as that of the diaphragm in a camera. When an object is illuminated too intensely, the iris automatically contracts to shut out some of the light. When there is too little light, the iris expands to let in all the light it can. We never feel the iris doing these things, though it takes some little time to do them. That is why we need a few minutes to get used to darkness or to very bright light. It may be that the reason why cats and owls see better in the dark than we do is that the iris in the eyes of these animals can open more widely and more quickly.

How the Eye Differs from a Camera

In some respects the eye is different from a camera. We have already mentioned the different method used in focusing. Another difference is that a camera needs a "finder" to locate its object. Of course eye pictures are not so permanent as camera pictures that have been developed and printed. Yet the retina retains an image for about one-sixteenth of a second, no matter how short the exposure may be. Since we cannot replace the retina as we do a roll of films, the images on it must not remain forever. But the fact that images are retained for a short time is very important. Upon this fact depends the possiblity of motion pictures. If we flash sixteen pictures a second, showing the progressive stages of a moving object, we produce an illusion on the retina which the brain interprets as a moving object.

Finally, the eye differs from the camera in that it sees images in color. The ordinary camera takes a picture in black and white only.

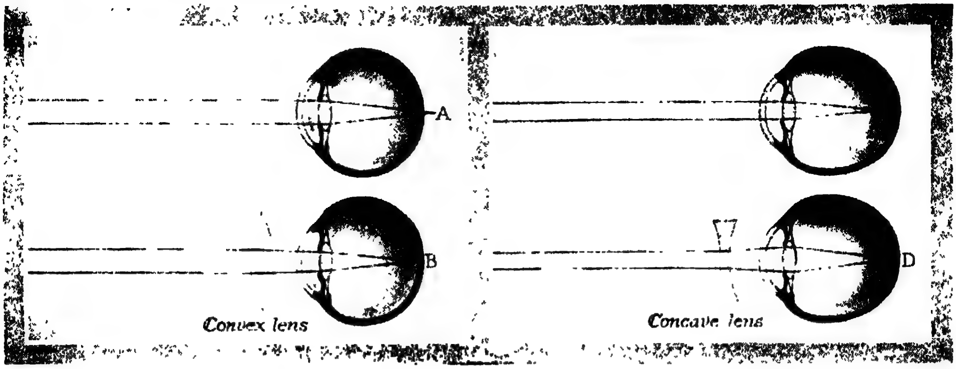
The Causes of Eye Trouble

Any defect or damage to the muscles, fluids, or nerves of the eye will have an effect upon our vision. A most serious defect, resulting perhaps in total blindness, is a damaged retina. Just as pictures cannot be taken without a film in the camera, so nothing can be seen without the retina. One may go blind, also, if the fluid in the lens loses its transparency and turns into an opaque crystal. In this case, no light can enter the eye, and of course vision is impossible.

Most eye troubles however, are due to poor muscular control of the lens or to a permanent curvature of the lens or cornea (kôr'nē-à) which the muscles cannot correct, or to a poorly shaped eyeball. If vision is to be perfect, the lens must focus images sharply on the retina. This is done by muscular action, tending to change the curvature of the lens. If the eye muscles are in poor condition and do not respond well, the lens may focus an image either in front of the retina or behind it. In the first case, the person is said to be nearsighted; in the second, farsighted. Often the muscles may be in good condition but the cornea itself may be so outward-bulging, or convex, that the muscles cannot flatten the lens enough to bring distant objects to a focus. Sometimes a case of nearsightedness comes neither from muscular deficiency nor from excessive lens convexity; but rather from an elongated eyeball. In that case the retina is so far removed from the lens that the image must fall in front of the retina. Farsightedness comes from conditions which are exactly the opposite of those just described. The eye lens or cornea may be too flat, or the eyeball may be too much fore-shortened.

When We Need Eyeglasses

What are the remedies? In a case of poor muscular control, one can massage or exercise the eye muscles to bring them back to normal functioning. Of course a doctor must say just how the eyes shall be exercised. Many cases of nearsightedness and farsightedness have thus been cured without resorting to eyeglasses. But when the defect is due to distortions in the eye lens, cornea, or eyeball, we must wear glasses to enjoy good sight. The principle of the glasses is rather simple. Since nearsightedness is due to over-convexity of the lens, an eyeglass that is concave in curvature must be placed in front of the eye. This will reduce the over-convexity and focus the image exactly upon the retina. A farsighted eye is supplied with a convex eyeglass, which



The two upper diagrams show the causes of two different kinds of defective vision. When the rays focus at point A, behind the retina, the eye is "farsighted"; when they focus at point C, in front of the retina, the eye is "nearsighted." In order to correct these defects, a convex lens—shown in the lower left-hand diagram—is used as an eyeglass for farsightedness. This brings the focus back to B, directly on the retina. A nearsighted eye requires a concave lens as an eyeglass—shown at the lower right. Again the focus is brought back to the retina, at point D. One's eyes usually become more and more farsighted as one grows older.

will increase the convexity and so again focus the image upon the retina.

There is still another common eye defect called astigmatism (ȧ-stĭg′mȧ-tĭz′m). In this trouble the cornea or eye lens is distorted along one direction or in some other peculiar way. In order to remedy the condition, an eyeglass is ground so as to be itself distorted in just the opposite way from the lens. When placed in front of the eye, it corrects the defect and provides good vision because the entire image, instead of part of it, is once more sharply focused on the retina.

The colors of the sunset and of the rainbow are among the most beautiful sights in nature. They make us grateful for the possession of eyes and may well impress us with the wonders of the mechanism by which we see.

But what is color? We may say that it is a sensation produced when a certain kind of light energy is received by the eye. Light energy is believed to travel through the ether in the form of waves. Different wave lengths produce different color sensations. Thus, a wave length of about one forty-thousandth of an inch produces red, while a wave of one sixty-thousandth of an inch produces violet. All the other colors are produced by waves of lengths that fall between those of red and violet.

The colors of the rainbow are somehow produced by the white light coming from the sun. So are the colors in a sunset, the colors in a fountain playing in the sun, the colors of sea shells, pearls, insect wings, and of soap bubbles. In every case, sunlight must fall upon the object in question in order that colors may be seen. It would seem, therefore, that the white light from the sun comprises all these colors in the first place; and that somehow this white light is separated into the various colored lights.

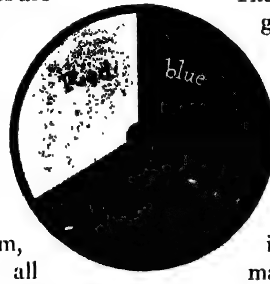
Anyone can break white light into colored lights by holding a glass prism in the path of a sunbeam. Newton was among the first to discover this, and to offer an explanation. He suggested that light does not travel so fast through glass or water as it does through air; and that a ray therefore bends as it enters obliquely from air into glass or into water. Now, light energies of different wave lengths are retarded in different degrees in glass or water. Hence the different wave lengths are bent by different amounts; so that when the beam leaves the prism, it is separated into beams of the different wave lengths or colors. If this "spectrum" of colors separated from a beam of white light is thrown upon a screen, we can see that the violet light is bent most by the prism and the red light least.

The rainbow is produced by the action of raindrops on the white light of sunshine. Each drop acts like a prism in separating

the white light. When the sun is at a certain height in the sky and the raindrops are falling through the air at a certain point, the rays are bent and spread out into their colors. The raindrops are constantly spreading sunlight into colors, but only when falling through a certain point are they in a position to send the colored light into the eyes of anyone on the ground. An aviator may see a rainbow when those below can see none. Rainbows are fairly rare because it is not often that sun, raindrops, and eyes are all in proper position.

A prism separates a beam of white light into the colors of which it is composed; but a convex lens, as we have learned, can be used to bring a divergent beam to a focus. If, therefore, a convex lens is held in the path of a beam separated by a prism, the different colored lights are all combined again. The result on the screen is a patch of white light where a spectrum band of colors would otherwise form.

The mixing of various colored beams may be studied by quickly rotating a disk on which the different colors are spread. Changing the amount of one or another color changes the color effect produced in the eye. Thus by rotating quickly a disk which is one-third red, one-third blue, and one-third green, we get a sensation of grayish white. The eye cannot see each of the colors separately, for the disk is moving too fast. Before the retina has lost the impression of the red, the blue light has combined with the red; and before this combination is gone, the green is also added. The three together, if present in the right proportion, produce an approximate white.



When this three-colored cardboard disk is rapidly spun, one can see neither red, blue, nor green. Instead, the colors merge, producing a grayish white.

Why Waves Have White Foam

The frothy white foam which is seen as waves break upon the shore, and the white appearance of snow, are examples of the combining of different colors. In the case of the waves, each water particle is really a transparent green. But when the wind whips the water into millions of tiny droplets, each drop of water reflects all the rays which strike it. The eye receives the combined effect, which is white. Similarly, each snow crystal is really a piece of transparent ice; but each crystal reflects so much of the light which falls upon it that the combined effect is a diffused white.

Everything looks rosy through rose-colored glasses. In other words, many different colored lights may strike a rose-colored glass, but only the rose light will pass through. The rest are absorbed. If the glass is green, the world looks green; and if the glass is blue, the world looks blue. In the theater, a red spotlight is produced by covering the source of white light with a sheet of red gelatin; and so for spotlights of other colors. Because so much of the light striking a colored glass is absorbed, many people wear colored eyeglasses in summer to reduce the intensity of the light. On the beach, where the strong sunlight is reflected to the eyes from all directions, people often use such glasses, usually colored a yellowish brown. The glasses rest the eyes by reducing the amount of light received. Explorers who travel for days over snow-white fields of ice under a glaring sun also resort to colored glasses to keep from going "snow-blind."

Why do objects have the color that they have? It is not easy to answer this question in full, but a part of the reason can be offered. A red book is red because it reflects red light to the eyes; a blue book reflects blue; and so on. It would seem, therefore, that the paints and pigments which cover objects absorb most of the white light which falls upon them. Each kind of pigment reflects but one set of wave lengths, absorbing all the others. The color we see is the color due to the wave lengths reflected and received by the eyes.

Then what would be the color of a red hat in a blue light? Since blue light is absorbed by a red object, no light at all can be reflected. The hat would look black; for black is the sensation that comes from the absence of all light. The fact that the colors

of objects depend upon the kind of light that falls upon them is used in many ways. It is of great use in the modern theater, where costumes and scenic effects often suddenly take on a wholly different appearance as a result of a change in the colors thrown on the stage.

People who try to match colors by artificial light are often astounded to find the next day that they have bought pieces of goods that do not match at all. Artificial light is usually lacking in some of the colors; and two different shades of green may look alike under an electric light. In the white light of sunshine, which contains all the colors, the two shades of green look quite different. That is why many shops that sell colored garments provide a special "daylight" lamp under which the customer may look at his purchase before deciding to pay for it.

During World War I we did everything we could to keep our ships from being seen by men on submarines. At first the ships were painted sea-green, in the hope that this would help to merge them into their background of ocean water. It was soon found, however, that a uniform sea-green color made a ship stand out more prominently. The explanation lay in the fact that the green of ocean water really contains other colors than green. Someone then thought of painting the ship with irregular splotches of different colors and shapes. The colors used were approximately those present in sea-green water and also those seen in the sky at the horizon. At a distance, it is not possible to see each of the colored splotches separately. The reflected rays were received by the eye as a combination similar to the one which comes from the water and sky. In this way, the ship was "camouflaged" (kăm'ōō-fläzh')—that is, hidden from view by being merged into its background. The same method was used in camouflaging cannon to make them difficult to see from an airplane.

This instrument, called a spectroscope, is one of the most valuable of all the instruments that scientists use. By means of it we are learning more about the secrets of the stars and the mysteries of matter. The heart of the instrument is a small triangular glass prism which stands on the platform between the two cylindrical telescopes.

The retina which receives the images that the eye lens produces is a very wonderful screen of nerve fibers. Unfortunately we do not know so much as we should like to know about the way in which it acts to change different light stimuli into color sensations in the brain. There are, however, several theories about the way in which the retina and brain work together to produce color vision. One of these is that the retina responds to only three colors of light. These are red, green, and violet-blue. When other colors are seen, it is due to the mixing of these three "primary" colors in various proportions. Thus the proper amount of red light mixed with the proper amount of green light produces the effect of yellow. Similarly, red light and violet-blue light may, when properly combined, give the sensation of purple. Green and violet-blue produce blue-green. The proper combination of all the three primary colors yields white. Sometimes two colors properly combined give the effect of white. They are then called complementary colors.

When Colored Pigments Are Mixed

Now all the above explanations hold for the mixing of light beams of different colors. When colored pigments are mixed, different results are obtained. We all know that yellow pigment mixed with blue-green pigment produces green. Similarly, yellow and purple mix as red. Purple and blue-green mix as violet-blue. When blue-green, purple, and yellow are combined, the result is black. The reason is interesting, and may be learned from an examination of any one of the pigment mixtures. Let us take the combina-

tion of blue-green and yellow into green. An object covered with blue-green pigment reflects only blue light and green light. An object covered with yellow light would reflect only yellow; though in practice it usually reflects also some green light because the yellow pigment is impure. If both pigments are mixed and spread over a surface, the yellow absorbs the blue and the blue absorbs the yellow. Only green remains to be reflected, and so the surface appears green. When we mix three pigments, such as green, purple, and yellow, all the colors are mutually absorbed, leaving nothing to be reflected. The effect is therefore black.

The Useful Spectroscope

If a vote were taken among men of science to name the instrument which has brought the greatest advances in our knowledge of the universe, they would undoubtedly select the one which measures the colors or wave lengths of light energy. That instrument is called a spectroscope (spĕk'trô-skōp).

A simple form of spectroscope consists of a glass prism on a circular platform. Surrounding it are two or sometimes three small telescopes. A beam of white light enters through a narrow slit in the end of one of these telescopes and falls upon the prism. The prism spreads out the beam into the colors of which it is composed, and the spectrum passes into a second telescope at the end of which is the eye of an observer. The eye sees a rectangular band of colors, ranging from red to violet by gradual changes through orange, yellow, green, blue, and indigo, or purple. If a third telescope is present, it contains an illuminated scale from which a beam of light strikes the polished surface of the prism and is reflected into the eye telescope. The eye then sees the band spectrum against a measuring scale, and so can identify any color by noting its position on the scale.

If, instead of a beam of white light, we permit the light sent out by a heated vapor to enter the slit, the eye will see a series of vertical colored lines. Each line is at a point on the scale to which its color belongs. Now the remarkable fact is that every one of the ninety-two elements of which matter may be composed produces its own peculiar set of colored lines. No two elements are alike in this respect. Thus, whenever two yellow lines, close together, are seen in a spectroscope, one may be certain that it is the incandescent vapor of the element sodium (sō'dĭ-ŭm) which is sending its light into the instrument. By this method an astronomer can examine the light from a star and tell with some degree of certainty what elements exist on that distant body. He may study, too, the composition of the sun.

From small beginnings the spectroscope has developed until to-day it is the most accurate and most fruitful means for studying bodies that are too far away for man to reach. If you have wondered how the tiny wave lengths of light can be measured, you will find the answer in the spectroscope. It is the spectroscope that furnishes the facts upon which many of the modern theories of science are based. It is this instrument, too, which provides the means for studying the behavior of atoms, molecules, electrons, protons, and neutrons—concerning which we shall have more to say later.

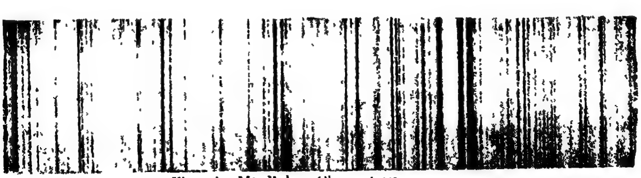


Photo by Mt. Wilson Observatory

Some such pattern of lines as this is what one sees through a spectroscope. But of course the band is colored, its precise shade or shades depending upon the substance giving off the light.

PHYSICS

Reading Unit
No. 20

HOW IS A SOUND MADE?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Edison's first phonograph, 1–443-45
What carries sound? 1–445
How sounding bodies vibrate, 1–445-46
1,100 feet per second, 1–446
Echoes, 1–446
The ear, 1–447
Changing the pitch of musical instruments, 1–448-49
Tone, 1–450

Things to Think About

How does a phonograph reproduce sound?
Why does not the ear hear all vibrations?
How does the ear change a sound wave into a message for the brain?
How is the speed of sound measured?

Picture Hunt

What organ is built without the use of either pipes or reeds? 1–449
How is the pitch of wind instruments controlled? 1–449
What are the parts of the ear? 1–447

Related Material

How do broadcasters imitate sounds? 10–119
How may sound be changed into light? 10–504, 506
How does a radio produce sound? 10–118
How do insects produce sound? 3–292, 337, 345-49, 372
How are ships safeguarded by sound waves? 10–229
How is sound reproduced in talking pictures? 10–504, 506
How does the ear maintain our sense of balance? 2–282-85
How may brain injuries affect hearing? 2–389

Practical Applications

How are phonograph records made? 1–443-45
How are the sounds of musical strings amplified? 1–449

Leisure-time Activities

PROJECT NO. 1: Make a string telephone, 1–447.
PROJECT NO. 2: Play a tune on an ordinary piece of pipe, 1–448.

Summary Statement

All sounds are produced by bodies that are vibrating at least 16 times per second and not more than 40,000 times per second.

When the boy shouts "hello" and hears his "hello" come back faintly from the church, he knows that what he hears is an echo. He knows that large surfaces, like the church of our picture, reflect sound waves. The dog is not so sure; he looks as if he would like to investigate the phenomenon!

HOW IS *a* SOUND MADE?

Every Noise You Ever Hear Comes from a Single Kind of Action in the Thing Producing It—Do You Know What It Is?

IF YOU had been present in the laboratory of Thomas A. Edison on a certain hot night in August, 1877, you would have seen a strange sight. There was the famous inventor, standing near a strange instrument; and around him, holding hands and dancing in a circle, were a number of friends and assistants. Now and then they stopped their excited singing and laughter while one of them whistled or shouted into the machine which shared with Edison the center of the stage. Then someone would turn a crank on the machine as they all listened to the faint and wheezy sound that it produced. When the sound was recognized as that of the person who had whistled or shouted, there was more rejoicing on the part of the group.

As you may guess, they were celebrating the latest of Edison's inventions, which had just received its first successful test. The phonograph had that day been given to the world. When the newspapers heard of it, their headlines carried the story throughout the land. At home and abroad everyone wanted to see and to hear the machine that could talk like a human being. Edison was compelled to build four hand-cranked machines for exhibition to satisfy the curiosity of the crowds that flocked to see them. If we could now hear the sounds produced by those first machines, we should probably turn away in disgust, so harsh and tinny were the effects. Yet the modern phonograph has been perfected from that first crude device.

Of course the machine could not be marketed until it was improved. The hand cranking soon gave way to a motor driven by a clock spring. The early tinfoil records vanished in favor of hard wax cylinders; and to make the original records more permanent, an electrical method was devised for plating the wax with metal. Finally a way was found of duplicating the "master" record, so that hundreds of copies exactly

like the original could be made for sale to phonograph owners.

An invention often comes by accident—but by the kind of "accident" that happens to a man of science. That is because the scientists know how to pave the way for it, and can see what it means when it comes.

That was the case with Edison and his phonograph. In the first place, he knew that sounds are produced when objects vibrate at certain speeds. He knew that the human voice is the result of a trembling throat muscle which sets the air in motion, and that the sound of a violin comes from a string shaking rapidly back and forth. Secondly, he was aware that the slightest change in a sound is due to a change in the vibration of the body that makes the sound. In other words, the voice of one person sounds different from that of another because the two sets of vocal muscles tremble differently when they produce sounds. Finally, he knew that if a body is made to shake like the vocal muscles when they produce human speech, then that body will give out sounds that can be heard as human speech. If one can force a stick to vibrate like a violin string, the stick will emit the same sounds as a violin.

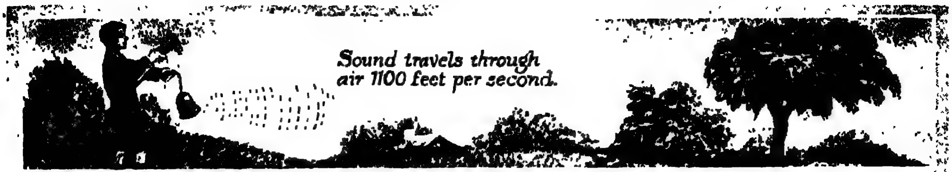
This is a photograph of Thomas A. Edison as a young man. Before him on the table is a model of the first phonograph he ever built. Note the cylindrical recording drum and the crude way in which it must be cranked.

How the Phonograph Was Invented

All the science of sound, or acoustics, Edison understood. So did many other men.

He was working with an improved telegraph instrument, trying to make each click of the sounder cut a dent in a moving paper disk. Each dot and each dash became a short or a long hollow, cut by a sharp tool. By making the tool move over the impressions in the paper disk, he was then able to send out the same signals automatically. By accident he rotated the disk rapidly. This made the tool jump up and down so fast that it became a vibrating body and gave out a sound. In a flash, the idea came to the inventor. Why not make the sound of a human voice shake the sharp cutting tool? If it could do so, and if there were some substance in which tiny indentations could be made, then the pitted surface of this substance would hold a record of the human voice. To reproduce the sounds, he could move a sharp needle over the dented surface. This would force the needle and anything attached to it to vibrate like the original vocal muscles which produced the sound.

With Edison to think was to try. He sketched a rough plan and asked an assistant to build a machine. This was soon finished. Wrapping a sheet of tinfoil around a metal cylinder and adjusting a sharp needle against the metal sheet, Edison started the cylinder revolving. Then bending forward with his mouth near a horn that could carry his voice to the needle, he shouted the poem, "Mary had a little lamb." The needle danced with the sound of his voice and pricked small dents in a spiral path around the tinfoil. Would these dents make the needle dance again, if he forced it to travel over the path once more? He would see. And the needle did dance! In passing over the indentations, it shook and quivered enough to produce a sound. The horn made



Most of the sounds we hear come to us through the air; and we have become accustomed to the fact that time must elapse before a distant sound can reach us. So if you were watching on the hill in the picture above, you would hear the bell an instant after you saw the boy begin to ring it.

If you were to put your ear to this steel rail at a point 16,360 feet away from the boy with the bell, you would hear the bell through the rail one second after the boy started ringing it; but you would have to wait about fifteen seconds for the sound of it to reach you through the air.

Here a deep-sea diver is ringing the bell under water. If you were swimming 4,800 feet away, and had one ear submerged and the other in the air, you would hear the same sound twice. It would reach you through the water a second after the hammer struck, and again through the air about 3 seconds later.

this sound loud enough for all to hear. The curious machine was talking. A small thin voice was saying: "Mary had a little lamb."

Think of the very different sounds one hears: the slamming of a door, the fall of a book, the clapping of hands, the rustle of silk, the screech of automobile brakes, the whistle of a locomotive, the splash of water, the creaking of new shoes, the howl of the wind. In every case the sound is produced by a body that vibrates. Can you identify the body for each of the sounds listed?

How Sounding Bodies Vibrate

One can be convinced that sounding bodies vibrate. Place your fingers on your throat as you talk or hum. Do you feel the windpipe tremble? Blow through two strips of paper held together between your fingers. You can see the vibrations of the papers as they emit their screech. Strike a tuning fork on the table and listen for its sound. Then grasp the prongs. Do you feel the quivering metal? If you push a sounding fork into a dish of water, the trembling prongs will splash and spatter the water in all directions. A stretched rubber band when plucked gives out a sound. You can also see it vibrate back and forth. There is a story of a man who yelled so loud that the noise dislodged a picture on the wall. His vibrating throat muscles caused the picture to shake too much.

All sounds are the result of vibrating bodies; but not all vibrating bodies produce sounds. By careful measurement scientists have found that an object must shake back and forth at least sixteen times a second in order to give out a sound that can be heard. But when a body shakes so fast that it goes back and forth more than forty thousand times a second, it ceases to give out a sound that human ears can hear.

We live in an ocean of air, with our feet

on the ground. We cannot move from place to place without pushing the air aside. Every object that shakes or quivers must also stir up the air. The newspaper which rustles noisily as we open it must, in doing so, produce puffs of wind, since the paper vibrates while giving out a sound. If one could see the air in a noisy room, it would look like a tossing and stormy ocean. These air waves have no effect upon the eye; but when they reach the ear, they are heard as sounds.

The fact that air is so easily set in motion makes hearing possible. The vibrating body pushes the air particles nearest it and these pass on the disturbance to those next to them. In this way the push finally reaches the air particles near your eardrum, which then vibrates in a manner similar to that of the sounding body. Hearing the sound is the result.

When an explosion takes place on top of the distant hill, the flash of light reaches the boy's eye almost instantly; for light can travel 186,000 miles in one second. But the sound of the explosion takes 10 seconds to reach him. This he finds out by timing the sound's arrival with a watch. Since sound waves travel through air at a speed of about 1,100 feet a second, the boy concludes that the scene of the explosion is 11,000 feet away.

Scientists have measured the speed of sound traveling through the air. They find that the temperature of the air has something to do with it, but that in general a sound covers a distance of about 1,100 feet in a second. This is practically as fast as a bullet from a rifle.

What Is an Echo?

We have all been amused, at one time or another, by the echoes we hear in large halls, or out in the open when there is a hill not very far away. We shout "Hello!" and after a brief interval an answering voice returns the shout. The echo is explained by the fact that the air disturbance caused by your voice travels outward until it reaches the hillside. There it is reflected back along its path, and so returns to your ears. Knowing the speed of travel of a sound disturbance in air, we can predict how soon an echo will return. At a distance of 550 feet from a mountain, the echo of your voice will return in exactly one second, since sound can travel twice 550 feet, or 1,100 feet, in a second.

The slowness of sound-travel as compared with light-travel is very clear to anyone watching a ball game from a seat high up in the grandstand. As the bat meets the ball, we hear nothing, though we see the ball fly out. Then, when the ball is already in the air, we hear the crack of the bat. The rays of light from the bat and ball reach the eye before the sound disturbance reaches the ear.

In stories about Indians we often read how they listen for the approach of horsemen by placing their ears to the ground. The solid earth can carry the sound disturbance caused by horses' hoofs better than can the air. The same fact may have led you to put your ear to a railroad track to listen for the distant rumble of a train. Steel rails are very good carriers of sound. Among the very best sound conductors is liquid water.

Many other facts like those described above lead us to the belief that solids and

This diagram shows what takes place when a ticking watch is held up to the ear. Study the picture as you read our story below, where the action of the important parts of the ear is explained.

liquids carry sounds better than gases. But a solid must be elastic if it is to carry sounds well. Try this experiment. Get a long stick of wood and place your ear close to one end while your friend scratches the other end lightly with a pencil. You hear the sound clearly. Now saw the stick in two and separate the cut ends by an air space of about an eighth of an inch. The air gap, no matter how small, carries the sound of the scratch so poorly that you hear nothing at the other end of the stick.

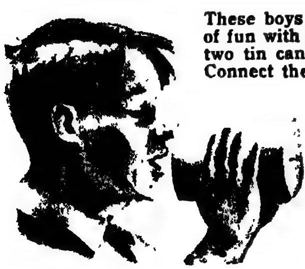
Can You Make a String Telephone?

Follow this experiment with a similar one in which you stretch a long string between the finger of your friend's hand and your ear. A pencil scratch at one end of the string is easily heard at the other end as long as the string is pulled taut. If the string hangs loose, however, no sound is carried through it. An amusing device is the well-known "string telephone." A stout string stretched between two open pill boxes carries the sound of the voice very well; but one must be sure that the sound carrier is tightly stretched.

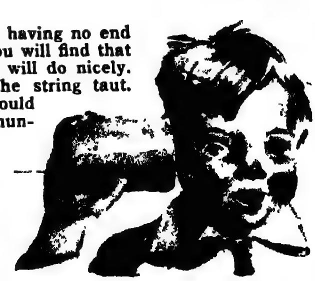
In each of the above experiments sound disturbances are carried more easily by substances that are dense and elastic. The stick is denser and more elastic than air. A taut string is more elastic than a loose one. When rooms in houses are to be made sound-proof, double walls and floors are installed. Between the walls and floors, soft or granular material is packed. In this way sounds cannot easily travel from room to room.

The poorest sound carrier of all is a vacuum, for in a vacuum there are no molecules at all to transmit a sound disturbance. On the moon, which is believed to have no atmosphere, there could be no noise. A charge of dynamite set off on the surface of the moon would be as silent as the hush of night. A whole mountain side might come tearing down, but the impact of stone upon stone would be as quiet as that of one feather falling upon another.

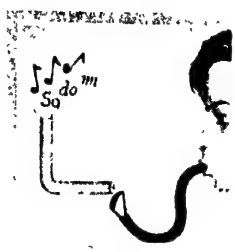
In one sense, there would be no such thing



These boys have made a string-telephone and are having no end of fun with it. If you should care to make one, you will find that two tin cans, pill boxes, or paper milk-containers will do nicely. Connect them with a string and be sure to pull the string taut. If it is well made, such a telephone should carry the sound of your voice for hundreds of yards.



as sound if there were no ears to receive and interpret sound disturbances. If all of us were deaf, vibrating bodies might cause millions of air ripples, but they would have no effect upon us. In fact, it may be said that all sounds involve three things: a vibrating body, some substance like air to carry the disturbance due to vibration, and an ear to receive and be affected by the disturbance.



By blowing through a spreader, such as is used to spread the flame on a Bunsen burner, one can cause the air in a bent glass tube to vibrate in several ways. In fact, it is possible to become so adept as to play upon the device as one would on a bugle. The tube should be about twenty inches long and a half inch in diameter. The picture at the right shows a half-inch glass tube which may be raised and lowered in a jar of water. In this case blowing will produce a tone of almost any pitch desired, according to the position of the tube in the water. The device may be compared to a trombone.

How does the ear act in receiving sounds? The picture on the preceding page shows the essential parts of the ear. Note that the human ear may be divided into three main parts: outer ear, middle ear, and inner ear. Now the outer ear, which is the horn-shaped portion that can be seen, is built in such a way as to gather in as many air ripples as possible. These ripples pass through a canal and strike the eardrum. This brings us to the middle ear. As the eardrum begins to vibrate with the impact of the air ripples, a series of small bones against which the drum rests also begin to vibrate. Thus, the disturbance is handed on to the inner ear. The inner ear is filled with a fluid, and is shaped like a spiral snail shell. The disturbance now travels round and round the spiral, sweeping by a series of nerve endings. Scientists cannot tell us exactly what happens at the nerve endings; but it seems that somehow they stimulate a large nerve which enters the brain. There the stimulus is interpreted as a sound.

Studying the picture of the human ear, one finds a canal leading from one side of the eardrum to the outer ear and another channel leading from the other side of the drum to the throat. This second channel is called the Eustachian (ū-stā'kĭ-ăn) tube. This tube must be kept clear if the drum is to vibrate freely. Sometimes this is not easy—as, for example, when one has a cold. Then the tube may be clogged and the free vibration of the drum be prevented.

The peculiar position of the drum between two canals makes great care necessary. Never pinch both nostrils in blowing your nose; for that may force air into the Eustachian tube and burst the drum outward. Blow one nostril at a time. The sound of a loud explosion may, in a somewhat similar manner, burst the drum inward. Soldiers firing cannon often keep their mouths open. This lets the air in on both sides of the eardrum and equalizes the pressure. If, when in a train, you feel your eardrums pressing inward as you ride into a tunnel, you may find relief by swallowing. In doing so, you push air into the Eustachian tube and equalize the pressure on the outside due to the sudden compression of air in the tunnel by the moving train.

The keys at the extreme right of a piano keyboard produce high tones. Those at the extreme left give low tones. We call the difference one of pitch. All musical instruments, as well as the human voice, are capable of producing sounds of varying pitch. When a violin plays a melody, tones of different pitch follow one another in a pleasing sequence and rhythm. The same is true in the song of a bird or of a human voice.

How the Pitch of Vibrations Varies

Now when does a vibrating body give out a high-pitched sound, and when a low-pitched one? Scientists have found that a high pitch is produced by a rapidly vibrating body, while a low one is the result of a slower vibration. The lowest pitch the human ear can hear is one coming from about 16 vibrations per second. The highest pitch comes from vibrations of about 40,000 times in a second. The key on the piano known as

"middle C" causes a certain string to vibrate about 256 times a second. The creak of a door hinge or the chirp of a cricket may be due to vibrations of over 20,000 times a second.

If we examine the different musical instruments, we find several ways of changing the pitch of the sounds they produce. In the case of stringed instruments, the pitch is raised when the string is either shortened or tightened. The pitch is lowered by lengthening or loosening the string. The thicker the string and the denser the material of which it is made, the lower the pitch. Thus, four things control the pitch of a sounding string: length, tension, thickness, and density of material.

In instruments like the trombone, organ pipe, and cornet, the vibrating body is a column of air. Here the pitch depends upon the length and width of the column, and upon whether the column is open at both ends or only at one end. The skill in playing a trombone lies essentially in being able to lengthen or shorten the air tube in order to produce the desired pitch. In a cornet a series of stops have the effect of changing the length of the vibrating air column. Blowing harder or less hard, in a certain manner, may also help the cornet player to produce sounds of differing pitch. Pitch in an organ depends largely on which pipe is sounded. Each tone requires a different pipe or air column.

Pitch is not the only distinguishing feature in a sound. Two sounding bodies may be vibrating at the same rate, and yet one may be so soft as to be hardly audible, and the other deafening in its loudness. What is the cause of loudness in the sound which a vibrating body produces?

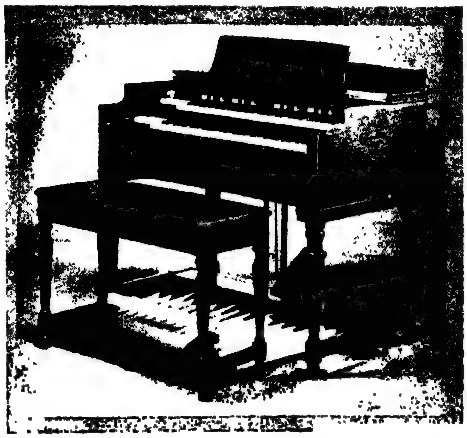


Photo by Hammond

The musical tones given out by an electric organ, such as the one above, are produced electronically. Only a few instruments rely on this principle. There are neither strings nor pipes nor reeds. The tones at first are electric waves, which are then turned into sound waves by the mechanism concealed inside the body of the instrument. One of the principal parts of the device is a small disk the size of a silver dollar, with "teeth" around its edge, much as on a gear. Driven by a motor, the disk revolves at an even speed, and is so placed that the teeth, or high spots, pass a coil-wound permanent magnet. As they do so they induce a tiny electric current in the coil. The process is explained in our article on electricity. If, for example, the high spots pass the magnet at the rate of 440 per second, when the current is amplified into sound we have a tone with a frequency of 440 vibrations a second—or the note we call "middle A." Each note on the organ has its own little disk.

It is the human ear which interprets a sound as loud or soft. Usually the force with which the eardrum is caused to vibrate determines the loudness of the sound heard. The eardrum is of course affected by the air ripples which strike it. The air ripples, in turn, are dependent upon how the body sending them vibrates. If the body swings through a wide arc, a forceful air ripple is started and the sound heard is loud. When the arc is narrow, a soft sound is the result.

Sometimes a sounding body forces a large object near it to vibrate with it. This object, being in contact with a large amount of air, produces a much larger air ripple than can the sounding body itself. So another way of increasing loudness is to force a large volume of air into vibration. This method is employed in a piano, where the sounding board reinforces the sound produced by the strings. The violin box also reinforces sounds, and so does the framework of the harp. The strings of a violin, piano, guitar, mandolin, or harp would sound very feeble without the sounding boards or boxes to which they are attached. The strings of a harp may vibrate through just as wide an arc as the strings of a piano, but the harp produces softer sounds, largely because its framework puts less air into motion than does the sounding board of a piano.

In the case of musical instruments that depend for their sound upon vibrating air columns, loudness and softness is again determined by the amount of air set in motion. That is why a horn is employed, for a horn incloses a large volume of air. Often a cornet player plugs up the horn when he wishes to reduce the loudness of his playing. To some extent, loudness and softness in this type of instrument depend also upon the force with which the player blows.

The Peculiar Quality of a Tone

Imagine yourself blindfolded in a room where there are many different kinds of instruments. Each instrument in turn plays a tone of the same pitch and of the same loudness. Can you recognize the violin? The piano? The mandolin? The trumpet? The saxophone? The human voice? Probably you can, because each instrument has its own peculiar quality. So there is another characteristic of sounds to be considered. In addition to the pitch and loudness of a sound, we must note its quality.

It is rather hard to say what it is about a sounding body which determines its quality. Speed of vibration explains pitch, and the amount of air set in motion determines loudness; but what accounts for the quality of a sound?

How a String May Vibrate at Several Speeds

Scientists and musicians who have studied this question tell us that a string or an air column—any object, in fact can vibrate at several different speeds at the same time. Thus, a string as a whole may vibrate 256 times in a second; but each half of it may at the same time be vibrating 512 times a second. The resulting sound is compounded of two sounds; the first overshadows the second, but both are heard. When a string or an air column vibrates at several speeds at the same time, one speed is fundamental, determining the main pitch and loudness; but the others also have their effect upon the listener. If the main pitch and the secondary ones harmonize pleasingly, the quality is pleasant, and we call the sound sweet. If the harmony is bad, the sound is harsh.

No two instruments have ever been made which have exactly the same quality, though they may agree perfectly in pitch and in loudness. A violin that costs $50,000 is different from one that costs but $10 because the former can produce sweeter tones. Somehow its builder has so adjusted the size, shape, and construction, and has used such fit materials, that the main and secondary pitches for every tone blend perfectly. The opera singer who receives $1,000 for an evening's performance possesses vocal cords whose main and secondary vibrations for every tone blend in a most pleasing manner One reason why we can recognize our friends by the sound of their voices is that we have learned to detect the differences in their vocal cord vibrations. No two sets of vocal cords vibrate exactly alike.

The Natural Vibration Rate of an Object

Did you ever find that some object in the room gives out a sound whenever a certain key on the piano is struck? It seems as if the object is in sympathy with that particular string. Since the string vibrates at a certain speed, it sends out air ripples that follow one another at that speed. These ripples strike every object in the room, but only one object responds by vibrating at the speed of the string. The explanation is that every object can vibrate best at a certain speed, called its natural vibration rate. We have already learned that this rate depends upon such things as size, shape, and kind of material. If, therefore, the air ripples strike the object at its natural rate, the object begins to vibrate.

All this may remind us of the process of starting a swing. Depending on the length of the ropes, the swing can vibrate just so many times a minute and no more. First, you give a little push which starts the movement. Then you time the second push so as to agree in direction with the moving swing. A third push, a fourth, still others, cause a wider and wider movement. We may therefore say that vibrating hands forced the swing into vibration because the natural rate of the swing was the same as that of the hands.

PHYSICS

Reading Unit No. 21

HOW CAN A FLY WALK ON THE CEILING?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The Magdeburg Hemispheres, 1–452-53
Why empty bottles are not really empty, 1–452
Walking on the ceiling, 1-452-53
Atmospheric pressure, 1 453-56
The stratosphere, 1–454
What is the weight of air? 1–454
The aneroid barometer, 1–455-56

Things to Think About

How does a fly use atmospheric pressure when it walks on the ceiling?

Why do balloonists seal their gondolas when they go up into the stratosphere?

Picture Hunt

What happens to a tin can when air is removed from it? 1 455
How high does our atmosphere reach? 1–454
How are changes in atmospheric pressure recorded continuously? 1 455

Related Material

How does atmospheric pressure affect the cooking of food on mountain tops? 1 402-4
How is the weather related to changes in atmospheric pressure? 1 259-61
How do changes in atmospheric pressure affect the eardrum? 2 304
How may trains and automobiles be stopped by the use of air pressure? 1-461-62
What makes an airplane rise? 10-315-28
When do meteorites begin to burn? 1–320-21
How may atmospheric pressure cause water to flow uphill? 1 459-60

Practical Applications

How does an aviator know his altitude? 1–456
How may air pressure be measured with a portable instrument? 1–456

Leisure-time Activities

PROJECT NO. 1: Show how atmospheric pressure can make a tin can collapse. 1 455-56.

PROJECT NO. 2: Make a barometer. 14 48.

Summary Statement

The atmosphere, because of its weight, exerts a pressure of about fifteen pounds per square inch at sea level.

The horses tugged and strained but all in vain, for they could not pull apart the two half balls which Guericke had fitted together. Yet only a few moments before, the balls had come apart quite easily! In this story you may learn why the two half balls came apart in the one case and not in the other. This spectacle was staged by Guericke before the court of Prince Ferdinand of Germany, in the town of Magdeburg. Ever since, the half balls have been known as the "Magdeburg Hemispheres."

HOW CAN *a* FLY WALK *on the* CEILING?

This Story Will Show How He Has a Way of Using the Weight of the Air to Help Him

WE ARE so accustomed to living in an ocean of air that we forget its existence altogether. We refer to spaces filled with air as "empty spaces"; and when forced to observe that it is a real substance, we watch with much curiosity and wonder.

So it was, not long ago, when a motion picture "stunt man" put on a show for the people in Los Angeles, California. Between two tall buildings on one of the busy streets a cable was stretched 390 feet in the air. The crowds below stopped long enough in their hurry to gape upward at a curious object, much like a suspended cable car, that was being pulled along on the trolley, high above the pavement. Powerful search-lights aimed their beams at the moving object; for the "stunt" was being performed at night. What the crowd saw was a suspended plate-glass platform that glistened in the light. Back and forth it ran on the trolley, and—the astonishing thing—from it was hanging a man, attached in some mysterious way to the under side of the platform. Head down and feet up, he seemed to be hanging by the heels and soles of his shoes, which were pressed against the glass. Back and forth he rode over the deep chasm, defying death and holding to his perch like a fly against the ceiling of a room.

SOME INTERESTING THINGS ABOUT AIR PRESSURE

The performace, from many points of view, was utterly useless and silly; yet it did serve to arouse in the minds of many people a good deal of curiosity as to why the man did not fall. Had they been able to examine the man's shoes, they would have found a very simple answer to their question. Each shoe was fitted with two stout rubber cups, each about four inches in diameter across the mouth. These were pressed against the smooth glass plate so firmly that no air could find a place between the rubber and glass. The contact was extremely close. The weight of the man could not break this contact held tight by the pressure of the air around him; and so the figure hung head down, in seeming defiance of the law of gravity. In reality, the upward force of the air against the shoes was more than enough to counteract the downward pull represented by the weight of the man. As we shall soon learn, the sustaining air pressure was probably about five times the man's weight, assuming that he weighed 150 pounds.

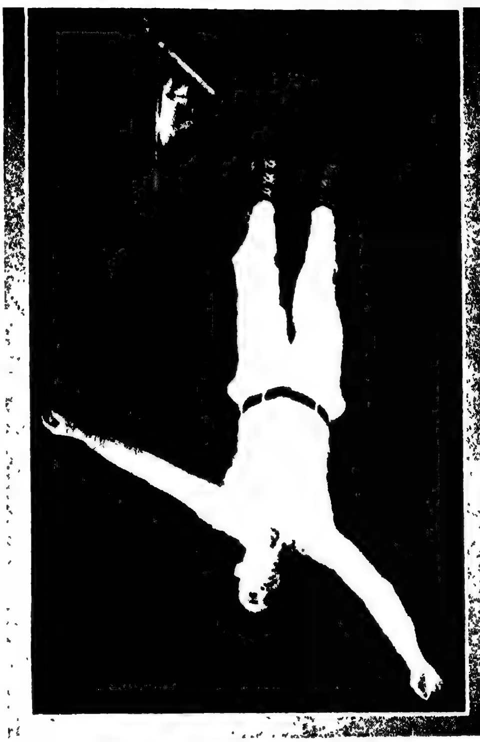


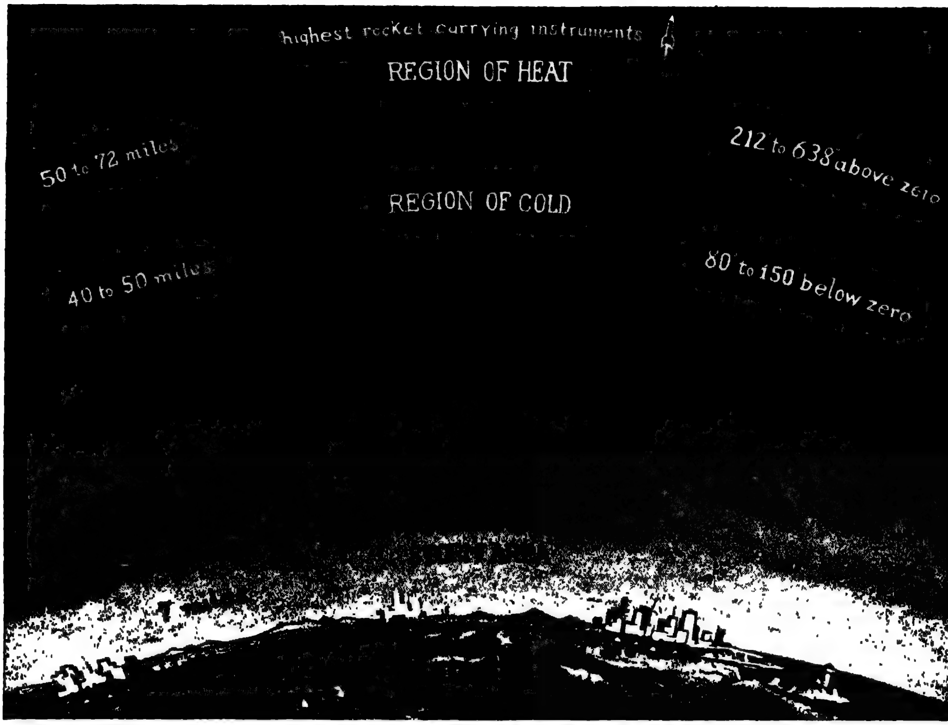
Photo by International News Photos

This is a picture of the daring "stunt" man about which our story tells. Think of dangling from a smooth glass plate 390 feet above the streets of Los Angeles! All that holds the man's shoes to the plate is the pressure of the air.

Guericke's Experiment in Air Pressure

This incident brings to mind a similar spectacle staged more than 275 years ago by the scientist Otto von Guericke (fôn gĕr'-ĭk-ē) in the days when modern science was just beginning. Even such a simple fact as that air exerts a pressure excited the wonder of men. But von Guericke did not need to dangle a human being from a height of 390 feet in order to prove his point. Instead, he built two brass hemispheres, each one foot in diameter across the open face. The two halves fitted nicely together to form a round ball; but their weight caused them to fall apart unless held together by an outside force. One of the halves was fitted with a stopcock to which a pump could be connected; and both halves were provided with rings to which a team of horses could be hitched. Having been asked by Prince Ferdinand of Germany to demonstrate his experiment before an assemblage of nobility, von Guericke first showed how easily one could pull apart the hemispheres. Then, fitting them together, he applied his air pump and drew out as much of the air as he could from the inside of the ball. At this point he hitched a team of horses to each of the rings and urged drivers to whip the animals into action, so as to pull the halves of the ball apart. The horses tugged and strained in vain. The pressure of air outside, holding the sphere together, was too much even for the horses.

In comparing the experiment of von Guericke with the feat of the "movie" actor, let us note that in each case the effect was produced by the pressure which air exerts. Moreover, each man depended upon hemispheres. In one instance these were four small hemispheres made of rubber; in the other case, they were two larger hemispheres made of brass. But there was a difference in the means by which the air was removed from the hemispheres; for the



How little we really know about our atmosphere is shown in the above picture. It would be thrilling to be able to go sailing above the region of storms. Some day, perhaps, we may mount even beyond the mysterious stratosphere into the still more mysterious portion of the air where meteors become visible.

modern stunt man did this by squeezing the rubber flat against the glass, while von Guericke used an air pump.

How Heavy Is Air?

"As light as a feather," we say when we wish to describe something that weighs very little. But if this feather should have billions of others piled upon it, anyone resting underneath the feather mountain might be squeezed to death. Similarly, we often say, "As light as air"; but we must not forget that the particles of air at the earth's surface have trillions of air particles on top of them, reaching up to a height of perhaps two hundred miles or more. The bottom layer of the atmosphere in which we live is somewhat like the bottom pillow in a pile of pillows. The lowest is the most compressed; the one at the top is the fluffiest. And the bottom layer of the air ocean is the densest, while at the surface of this ocean—if it has a surface—the air is rare indeed.

A cubic yard of air, at the level of the sea and when the temperature is just cold enough to freeze water, weighs about two pounds. A cubic yard of air taken at a higher level weighs less. But the warmer the air gets, the less it weighs, since heat causes air to expand, or become thinner.

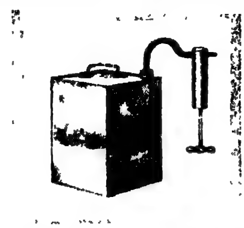
Why Air Exerts Pressure

Nevertheless, the air in a warm bedroom high up in a tall building must have considerable weight. If the dimensions of the room are 5 yards by 4 yards by 3 yards, the volume of the room is 5 times 4 times 3, or 60 cubic yards. If one could take these 60 cubic yards of air and place them on a weighing scale, where the rest of the air ocean could not press down upon them, the scale would undoubtedly register more than 100 pounds. Of course, such a thing could not easily be done. Besides, the weight of the air in a room is not so important to us as the combined weight of the roomful of air and

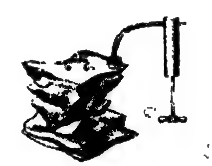
of all the air that presses down upon it, reaching up to the very top of the atmosphere which surrounds the earth. That is why we shall speak more often of air *pressure* than of air *weight*; although air exerts a pressure only because it has weight.

On other pages in these books we have told you how Torricelli, a pupil of the famous Galileo, was able to find a simple and accurate means of measuring the pressure which air exerts upon every object against which it rests; and how, by means of this device, he was able to prove that the pressure of the air about us varies from hour to hour and that it is greater at sea level than on a mountain top—a thing that is only natural since at sea level there are a good many more cubic feet of air above one's head than there are on a mountain top. Torricelli found that at sea level the air exerts a pressure of about fifteen pounds on every square inch of surface against which it rests. Let us remember this fact.

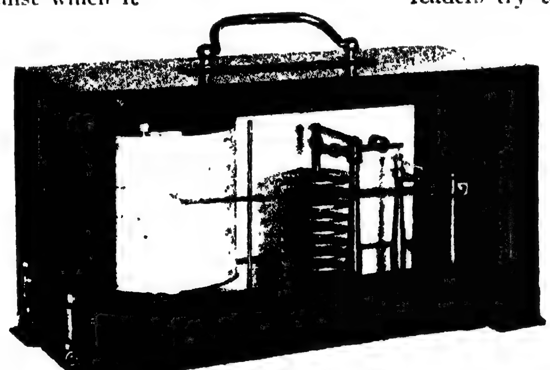
When the "stunt man" advertised the show which was described at the beginning of this chapter, he referred to himself as the "human fly." He was quite right, not merely because he resembled a fly as he dangled from the glass plate, but because the house fly can also attach itself to walls and to ceilings by means of "cups" at the ends of its feet. These cups when pressed flat force out the air from within, so that the air outside can exert its pressure of 15 pounds on every square inch of surface pressed upon by the cups.



A suction pump is attached to the single hole in an empty can. By operating the pump, one can draw most of the air out of the



This is what happens to the can when the air is drawn out of it. The pressure of the air outside the can forces in the walls, and the can crumples.



This instrument, known as a barograph, automatically records the pressure of the air from minute to minute throughout the week. The cylindrical drum upon which the pen point is tracing a line is moved by clockwork the spring of which must be wound up every seven or eight days. The strange-looking device in the center is a barometer of the aneroid type.

Let us now see how large an air pressure supported the stunt man. Each of the four cups had a diameter of 4 inches. From this it may be calculated that the man's shoes made close contact with about 50 square inches of area on the glass plate. Since the air exerts a pressure of 15 pounds on every square inch, its pressure on 50 square inches is 50 times 15 or 750 pounds. So if the man weighed 150 pounds, the air pressure was about five times as great as his weight.

One might well ask, "Why can't a person hang from the ceiling by pressing his palms flat against it?" The reply would be that he could if he were able to make such close contact with the ceiling that every molecule of air was removed between the ceiling and his palms. Of course he would have not only to exclude the air from those spaces, but to keep it out after he had once removed it. Should any of our readers try to imitate a fly by pressing his hands against the ceiling, he will soon find that the palms offer very poor means for making a good contact, and that it is impossible to prevent the air from creeping into the space between the hands and the ceiling.

To get a clearer idea of all this, try this simple and interesting experiment. Get a small rectangular tin can such as is used for varnish or for oil. It should have one round opening at the top. Fit a cork into the opening, and be sure that you can quickly insert this cork and that it is tightly wedged. Now

remove the cork and pour a little water into the can. Place the can on the stove, and bring the water to a boil. When the water has been boiling for some time and you are certain that the steam has pushed out all the air, quickly insert the cork and remove the can from the flame. Keep the can in a cool spot, or help it to cool by sponging the outside surface with a wet cloth. In a little while the steam left inside the can will condense, and a partial vacuum —or airless space—will be formed inside the can. Now there is almost no pressure inside the can to withstand the pressure exerted by the air on the outside of the can; so at this point, the can will crumple up into a bent and twisted mass of metal, as if some giant's hand had squeezed it into a lump.

Why the Can Crumpled

If the surface area of the six sides of the can totals 200 square inches, the pressure of the air would be 200 times 15 pounds, or 3,000 pounds. No wonder the can crumples!

In our discussion of air pressure we have been careful to say that the pressure of air is fifteen pounds per square inch only at sea level. The higher up one goes, the smaller is the pressure. In fact, for the first mile or so, every nine hundred feet one climbs brings one into air that exerts a pressure of half a pound less per square inch. But the higher one gets, the slower is this rate of decrease in pressure.

Now when a balloonist or an aviator climbs six or seven miles into the air, the decreased air pressure at such a height causes him great discomfort and even danger. Not only is there not enough oxygen for breathing purposes, but the body cannot accustom itself quickly enough to the low pressure around it. The heart is used to pumping blood through the arteries with a force sufficient to overcome the 15 pounds per square inch which, at sea level, constantly grips the body. When this external air grip is suddenly reduced to 10 pounds per square inch or even 5 pounds per square inch, the heart in its continued and forceful pumping may burst a blood vessel. Mountain climbers and aviators sometimes find themselves bleeding from nose and mouth on account of this sudden drop of air pressure at high elevations.

Professor Piccard's Experiment

Recognizing this difficulty, Professor Piccard (pē'kär'), when he not long ago climbed some ten miles above the earth, inclosed himself in a strong metal ball, which he sealed tightly after entering it. Inside, he maintained a more normal air pressure by releasing oxygen from tanks as it was needed. After reaching a height of more than ten miles, it would have been suicidal for him to open the porthole. He did not dare open the ball until he had descended to a height of three or four miles.

The modern "stratoliners" are equipped with "pressurized" cabins—that is, airtight cabins in which, as the ship cruises several miles high through the thin air of the substratosphere, the air inside the cabin is compressed until the pressure is comfortable. Oxygen too is supplied.

Torricelli's invention for measuring the force exerted by air gave rise to the modern barometer (bȧ-rŏm'ē-tẽr), an instrument which we have described elsewhere. It has become a necessity in predicting the weather. Aviators, mountain climbers, and explorers need a compact, sturdy, reliable, and easily read instrument, so they commonly use what is called an aneroid (ăn'ẽr-oid) barometer. A form of this used by aviators is known as the altimeter (ăl-tĭm'ē-tẽr).

The Principle of the Aneroid Barometer

In principle an aneroid barometer consists of an inclosed metal drum one side of which is flexible. The air inclosed in this drum does not communicate with the air outside. So the pressure of the air inside does not change much, but the pressure of the air outside may change. Should the air outside increase in pressure, the flexible side is dented inward. Should it grow less, the flexible plate is pushed outward. This inward and outward movement operates a lever which moves a pointer over a scale. The scale is marked off to indicate the amount of air pressure.

PHYSICS

Reading Unit
No. 22

HOW WE PUT THE AIR TO WORK

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is compressed air? 1–458
What causes liquids to flow out of a can? 1–458
What is reduced air pressure? 1–458, 463
What makes water flow uphill? 1–459
How is water kept out of tunnels under construction at the bottom of rivers? 1–460-62
How does air stop our trains? 1–461-62
What makes a vacuum cleaner work? 1–463

Things to Think About

Could we dig tunnels under water without using compressed air? Why not?
Could we breathe if there were no air pressure? Why not?
What is the danger to men who are working under heavy air pressure?
Could water be supplied to large cities without the use of air pressure?

Picture Hunt

How is a train stopped? 1–461
How does a pump work? 1–464

Related Material

What made safe railroad transportation possible? 1–461, 10–200
Why is air pressure important for the automobile? 1–462, 9–260, 270
How does air pressure help make the weather? 1–259-61
Why is it hard to cook an egg at a high altitude? 1–402-4
How does air pressure affect the wind? 1–222-25, 399
How does air pressure make it possible for man to travel by airplane? 10–315

Practical Applications

How is air pressure put to work in each of the following devices: air brakes, sand blasters, pneumatic drills, vacuum cleaners, automobile tires, pumps, fountain pens, and pneumatic chutes? 1–458, 465, 10–200

Leisure-time Activities

PROJECT NO. 1: Make some trick bottles, 1–458-60.

PROJECT NO. 2: Make a siphon, 1–459.

Summary Statement

Breathing, and the operation of many industrial and home devices, depend upon "putting air pressure to work." For these purposes we use both compressed air and reduced air pressure.

What good is a basketball if it is not blown up? These boys are smiling in anticipation of the fun they are going to have when the pump has forced enough air into the bladder.

Photo by H. Armstrong Roberts

HOW WE PUT *the* AIR *to* WORK

What Is the Secret of Nature That We Use in a Pump or a Vacuum Cleaner?

THE work which air may do in the world about us is of three chief kinds. First is the use to which normal air pressure is put. Normal air pressure is considered to be about fifteen pounds per square inch. Second is the use to which air may be put under compression. For air may be so crowded together, or "compressed," that its presssure mounts into hundreds of pounds per square inch. Such air can perform gigantic tasks. Third is the use to which we may put decreased air pressure—that is, air exerting a pressure of less than fifteen pounds per square inch. Sometimes its pressure may be reduced to almost nothing at all. When we want to make use of decreased air pressure we employ a partial vacuum.

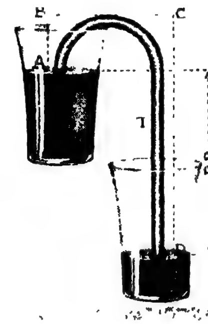
In each of the paragraphs below, you will find an illustration of the way in which the normal pressure of the air about us may be put to good use.

The picnic lunch concluded with delicious coffee; but, as no cream was available, a can of condensed milk was produced. "Here," said someone, "let me punch a hole in the can." Using a stone as a hammer, he drove a nail into the top. He removed the nail and inverted the can over a cup of coffee. To his surprise, not a drop of milk flowed out. "Let me have the can," said his neighbor. "The trouble with you is that you don't know how to take advantage of air pressure." Thereupon, he hammered another hole in the can. The can was inverted again, and the milk soon dripped out of one of the holes. Nothing came out of the other hole.

The "hike" was a long one; the day was hot and humid; and the road was full of dust. The troop of Boy Scouts welcomed the suggestion of their scout master that they halt for a while, to cool off and to wet their parched throats. In a jiffy, every canteen was out of its case, with open ends resting against mouths held high in the air. "I

wish I could get a real drink from a glass," said one of the boys. "This gurgling can doesn't give a fellow a decent chance to quench his thirst." "That's just the point," said the scout master; "one shouldn't drink too much under these conditions. That is why canteens are built as they are. Air must get in through the narrow opening before water can come out. You can get enough to rinse your mouth and occasionally enough to gulp down. The canteen protects you against yourself."

A carelessly planned camp fire was threatening to catch in a large bush. There was danger of a forest fire. "Quick!" yelled one boy. "Grab every can and bottle and run to the stream for water!" Two boys came back, one with a small but open can full of water and the other with a very large but narrow-necked flask. The can of water emptied itself immediately upon the blaze; the flask spurted its contents intermittently upon the flames, trying the patience of the holder to the point of exasperation. "This is no good!" he cried. "Break off the neck, to let the air in," someone advised. He did so; and the water poured out easily.



This shows how a siphon works. When the tube, T, is filled with water, the liquid in glass M will flow into glass D. The pressure due to the difference in water levels, BB, is the effective force which overcomes the air pressure and causes the water to flow.

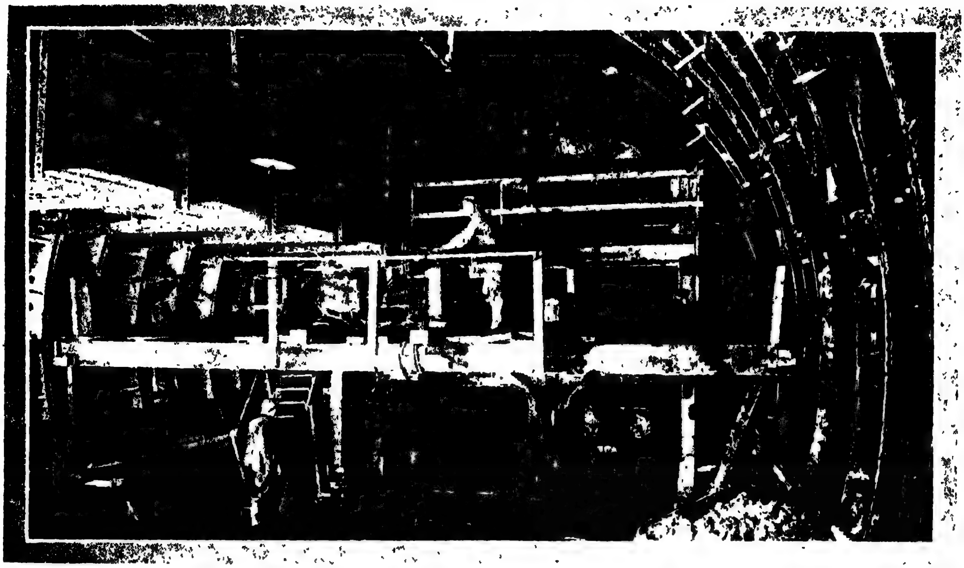
How Air Pressure Acts on Liquids

"I have a 'trick' bottle," said Sam. "It is full of water and has a hole in the bottom; but the water does not flow out." Sam held up the bottle for his friend to see—but he kept his finger plugged into the neck. "Why don't you take your finger out?" asked his friend. "When I take my finger out, the water spills. See!" Now how can closing the opening at the top of the bottle keep the water from running out at the bottom?

The teacher tied a strip of cheesecloth over the mouth of an empty flask. Holding the flask under a faucet, he allowed water to flow through the fine openings of the cloth and into the flask. He stopped when the flask was about two-thirds full. Then he quickly inverted it. The class was astonished to see that the water remained in the container, apparently supported by nothing but a sieve. Slowly the teacher tipped the flask at an angle. Air bubbles gurgled their way up through the water, as drops of water dripped out of the flask. But when the flask was held squarely upside down once more, both the air and the water stopped flowing.

It was time to change the water in the aquarium; but the vessel was too heavy to tilt. Besides, the fish might be spilled out if the tank was emptied in that way. Jack was puzzled. "Why don't you siphon out most of the water?" asked his father. "What do you mean by 'siphon out'?" was the reply. Jack's father then got a large pail, which he set upon the floor, and a rubber tube long enough to reach from the aquarium to the pail. Holding one end of the tube under the faucet, he filled the tube with water. He pinched the rubber at about the middle and, holding it there, carried it to the aquarium. Strangely enough, the liquid did not spill from the ends of the tube, which was hanging with the open ends downward. Quickly, and never releasing his hold on the middle of the tube, Jack's father placed one end in the aquarium and the other in the pail. Only then did he let go. The water in the aquarium soon began to flow steadily into the pail.

Now in each of the six paragraphs above, we have watched the action of normal air pressure in causing liquids to flow. The second hole in the milk can permitted air to enter and force out an equal volume of milk. In the case of the canteen, the inrush of air retarded the flow of the water—and yet no water could leave unless air first entered. So the water gurgled out. In the third instance it was found necessary to break off the neck of the bottle in order to provide greater space for air to enter and water to leave. The "trick" bottle, which our readers may try to make, shows clearly



The Holland Tunnel is one of the greatest feats of modern engineering. Here is a picture of the inside of the tunnel when it was first being pushed through the muck beneath the Hudson River. In order to keep the water from filling the tunnel, compressed air was used to counteract the water pressure. The men working in the advancing tunnel were of course compelled to breathe this highly compressed air.

how normal air pressure acting through the open neck upon the surface of the water, forces the water out through the hole at the bottom. Corking up the neck prevents this force from acting at the top, and the same air pressure acts through the opening at the bottom to keep the water from running out.

An Easy Experiment in Air Pressure

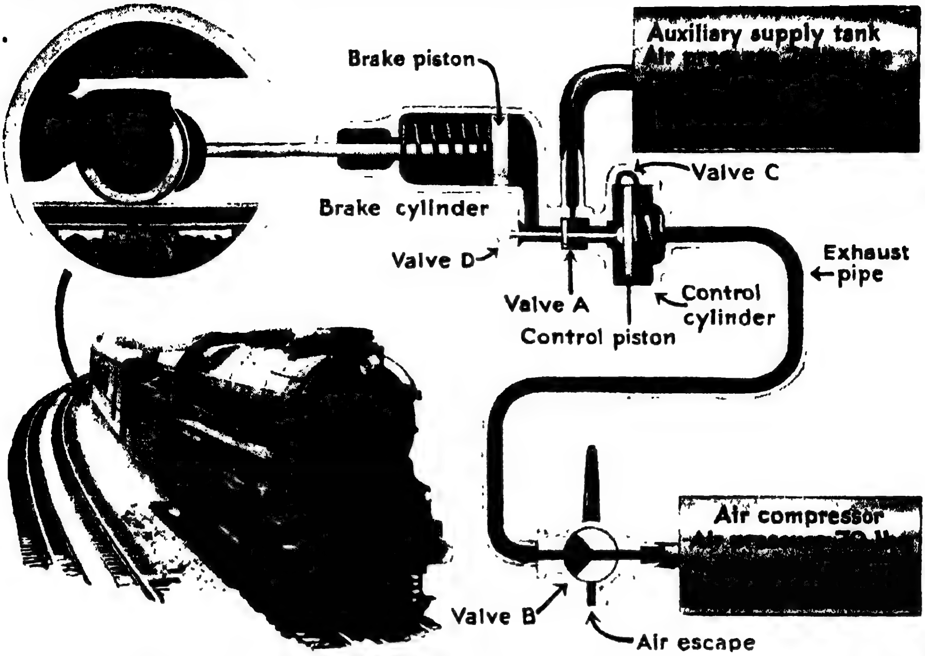
The cheesecloth-covered bottle enables one to perform another easy experiment. One can fill the bottle through the cloth because the air leaves through the mesh at one point as water enters the mesh at another. When the flask is turned upside down, the strands of the cloth help the water to form a continuous film at the bottom. The surface tension of this film acts to keep air from getting into the bottle; and so the water does not spill. The film is weakened by tipping the bottle at an angle. When the bubbles enter, an equal volume of water must leave.

The siphon is one of the most interesting applications of the use of normal air pressure. This pressure served to keep the tube filled with water when Jack's father carried the tube with open ends downward and the middle pinched shut. When the tube is released, the pressure of the water in the long arm reaching down to the pail overcomes the upward action of the air pressure at the bottom. The air pressure upon the water in the aquarium can then push the water up into the tube, and over the side of the tank. From that point, gravity causes the water to fall into the pail.

In a previous chapter we told of the difficulties and dangers encountered by men who go down under water to raise sunken treasures or to study forms of marine life or to lay the foundations for bridges and tunnels. They must have air to breathe, and they must in some way push aside the waters which press upon them with tremendous force. These problems are overcome with air that is highly compressed.

Digging Tunnels under the Hudson

In October, 1920, a gang of workmen began digging four shafts, two on the New York side of the Hudson River and two on the New Jersey side. At a depth of 70 feet below the surface of the river, the shafts turned into horizontal tunnels. The plan



The modern railway and the subway would be impossible were it not for the quick and powerful air brakes which can bring heavy trains to a stop. When a train or a trolley pulls into a station, one often hears the hiss of escaping air. It is followed by the chugging sound of a motor-driven pump which automatically replenishes the supply of air that was used up in stopping. In the picture above, you can see the compressed air tanks, the lever controlled by the motorman or engineer, and the piston which pushes the brake shoe against the car wheel. In this picture the brake is off and the air in both tanks is at the same pressure because valve C—which connects one tank with the other—is open. Now when the motorman turns the lever at valve B to the left, valve B shuts off the air compressor tank and allows the air from the exhaust pipe to escape suddenly—that was what made the hissing noise. The pressure on the left side of the control piston is now greater than the pressure on the right side, and the air from the auxiliary supply tank pushes against the piston and forces it to the right before any great amount of air can escape through valve C. At the same time, valve A moves to the right, valve D is closed, and the air from the auxiliary supply tank rushes against the brake piston. As this is shoved to the left, the brake shoe is pushed against the car wheel. Air brakes will bring a car to a stop in an amazingly short space of time. They have another, perhaps even greater, advantage. In case of accident—if a set of cars breaks away from the train or if anything happens to the connecting pipes—air is at once let out, the brakes are clamped on, and the train comes to a stop. All this makes air brakes very reliable.

was to have these tunnels meet under the river, so that two continuous passageways, each about two miles long, would be formed for the heavy automobile traffic that, before that time, had been able to cross the river only on ferries. The digging proceeded until a point was reached where the waters of the Hudson threatened to seep through the mud and silt and flood the tunnels. Then it was that compressed air had to be used.

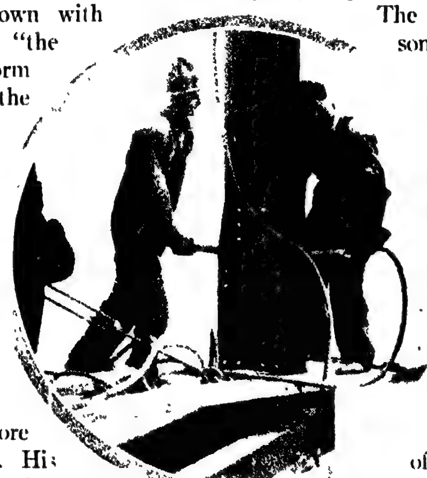
The Danger of Working in Compressed Air

At high tide, the Hudson River stands 100 feet above the tunnel that was being dug. The water pressure in the tunnel was therefore about 50 pounds per square inch. Added to this was the air pressure of 15 pounds per square inch acting upon the surface of the river. In all, 65 pounds per square inch were necessary to keep the water out of the tunnel. Pumps compressed air to this point and forced it into the forward ends of the advancing passageways.

The workmen were obliged to work in this atmosphere, which produced strange effects upon their bodies. Their lungs took in much more oxygen and nitrogen than they were accustomed to. The oxygen burned their food so rapidly that they seemed to possess superhuman energy; but they tired so quickly that two hours a day was all they could

work. The excess of nitrogen dissolved in their blood and gave rise to grave dangers when they left their work. In fact, their departure from the tunnel had to be very slow; otherwise, the nitrogen gas would accumulate in their veins and arteries and cause terrible and paralyzing pains. Many of the men came down with "caisson disease"—or "the bends"—which is a form of paralysis caused by the bubbles of nitrogen gas that do not leave the body.

It took seven years to complete the tunnels, which are now carrying 50,000 automobiles every day from shore to shore. Clifford M. Holland, the engineer, died of overwork two years before the tunnel was opened. His life and his genius have been honored by naming his great work of engineering the "Holland Tube." It stands to-day not only as a great monument to engineering skill and to courageous men, but to the service which compressed air can render to mankind.



It might be said that a modern skyscraper is put together, not by workmen, but by compressed air. The steel girders which support such structures must be riveted together. The hammers which pound the hot rivets with such tremendous blows are driven by compressed air.

Just as compressed air is used in the digging of under-water tunnels, so it is also used in laying the foundations for bridge towers. The George Washington Bridge across the Hudson River is supported by two gigantic towers that were firmly embedded in concrete while compressed air pushed the water aside. Deep-sea divers and submarine navigators call upon compressed air to protect their lives while they explore hidden depths.

The Uses Man Makes of Compressed Air

Our readers may be surprised to learn that the modern railroad and the subway would be impossible were it not for the quick and powerful brakes which can bring heavy trains to a stop. The power for these brakes is furnished by compressed air. Perhaps you recall the hiss of escaping air which is heard when a train or trolley car pulls into a station. Immediately after, one hears the chugging sound of a motor-driven pump, which automatically replenishes the supply of air that was used up in stopping. The pump stops when the air tanks are full.

The brick walls of houses are sometimes cleaned by a sand blast driven by compressed air; and the same driving force operates the hammer that rivets steel girders together. Hardened pavement is chopped to pieces by air-driven picks; and mountains of rock and coal are drilled through with the force of air under pressure.

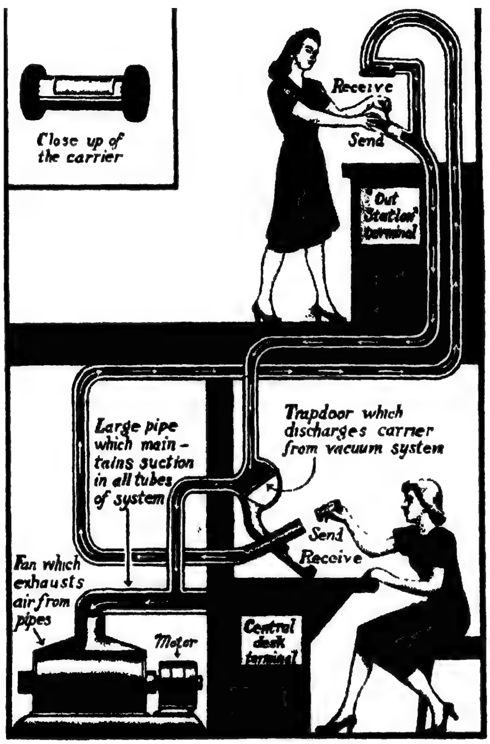
The dentist uses a blast of air to brush away particles of the tooth which he is drilling, and the doctor uses compressed air in measuring the pressure of your blood. The furrier and the carpet cleaner blow dust out of fabrics and the jeweler similarly blows dirt out of a watch with compressed air. Even the artist has found a use for air pressure when he uses it to spray paint with an "air brush."

A long, perforated pipe through which a stream of air bubbles can escape is sometimes stretched under water offshore, in order to reduce the fury of the waves. Finally, it is compressed air in the tires of an automobile which makes our ride so comfortable.

In the middle of the seventeenth century an important law was discovered by Robert Boyle while he was experimenting with compressed air. He found that the pressure of a gas and the volume that it occupies at any temperature are related to each other in a definite way. If the pressure is doubled, the volume is halved; if the pressure is tripled, the volume is reduced to one-third of what it was before. This relationship Boyle ex-

pressed in the following manner: "At a constant temperature, the pressure of a gas is inversely proportional to its volume." Let us apply this law to a definite situation. If a roomful of air is crowded by a pump into a tank one-tenth the volume of the room, the pressure of the air is increased ten times. Since the normal air pressure is 15 pounds per square inch, the compressed air in the tank is at a pressure of 150 pounds per square inch.

The act of breathing is an excellent illustration of how a reduced air pressure may be of service to man. As one takes a deep breath, the chest is raised and the diaphragm is lowered. This has the effect of increasing in volume the cavity around the lungs. An increased volume means, according to Boyle's Law, a decreased pressure. Let us say that the pressure in the cavity surrounding the lungs is 12 pounds per square inch, instead of 15 pounds per square inch. The normal air pressure in the room will make the air rush in through the nostrils to inflate the lungs.



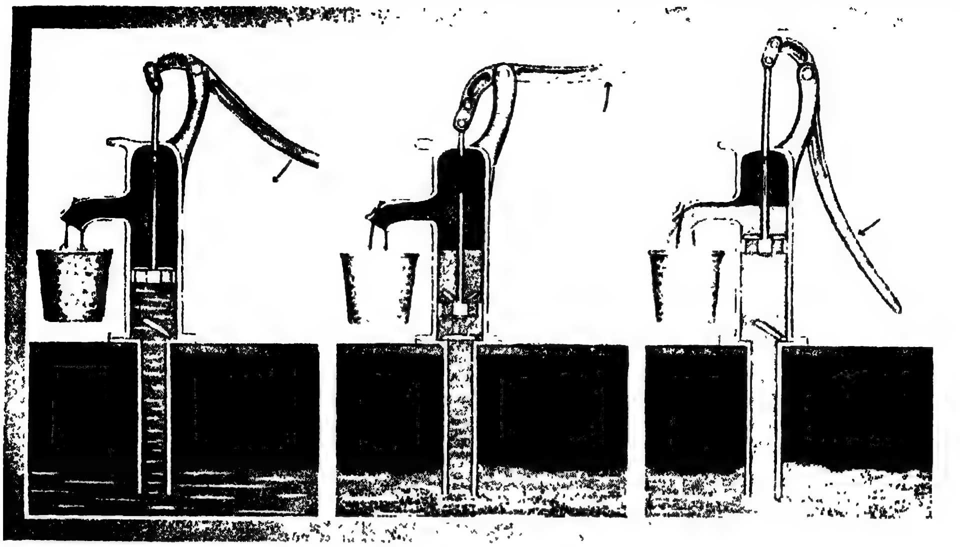
You may have been in a large department store where the clerk puts your money in a carrier that is then inserted in a pipe which rises above the counter. A moment later the carrier pops out through another pipe at your counter. In the carrier are your receipt and your change. The carriers are pushed through the pipes by means of normal air pressure acting on only one side of the carrier. The air pressure on the other side of the carrier is reduced by exhaust fans.

And what happens in a medicine dropper or a self-filling fountain pen? Here, a rubber bulb is first squeezed flat so that the air it contains is pushed out. We see the air bubbling up through the liquid. Then the rubber, which is elastic, regains its former shape; that increases the volume inside it. An increased volume is, of course, followed by a decreased pressure; and the normal air pressure on the liquid surface pushes the medicine into the tube or the ink into the pen.

In the case of a vacuum cleaner applied to a rug, a rapidly moving fan blows the air away from the top of the rug and into the bag. For just an instant, the air pressure above the rug is thus reduced. The normal air pressure then rushes toward the region of reduced pressure. In doing so, it blows through the fabric, carrying the dust and dirt with it to the bag.

The post office, too, makes use of reduced air pressure in sending mail containers through tubes that in certain sections of large cities stretch under the streets from station to station. A partial vacuum—that is, a reduced air pressure—is created by pumps on one side of the mail container. Normal air pressure on the other side pushes the container along through the tubes. The same system is also employed in certain large department stores for sending order slips and purchase money from counter to central office. Public libraries, too, often use this method for sending communications from the reading room to the book stacks.

Interesting things may happen under decreased air pressure. Place a four-inch piece of glass tubing, open at both ends, in a glass



This diagram will explain to you how a lift pump works. During the upstroke of the piston in a lift pump, the foot valve opens to let the air pressure push water through and up into the cylinder, as is shown at the left above. During the downstroke of the piston, the foot valve closes and the piston valve opens to let the water pass through to the cylinder above the piston. This is shown in the center of the picture. During the next upstroke, more water is pushed in by the air, as in the previous upstroke; and the water in the upper part of the cylinder is lifted high enough to flow out of the spout into the pail—as shown at the right.

of water, leaving one end out of the water. Now blow sharply through another such tube held close to the projecting end of the first tube and nearly at right angles to it. Note the spray of water which is created; it resembles the effect obtained with a common atomizer. What is the explanation?

When you blow a rapid stream of air across the top of the tube in the water, you create a region of reduced air pressure inside the tube at that point. The normal air pressure acting upon the surface of the water in the glass, pushes the water up the tube until particles of water reach the rapid stream of air. They are caught in the stream and forced into a spray.

The dentist often needs to keep the mouth of his patient dry. In order to draw out the saliva which constantly flows into the mouth, he hangs a little tube over the patient's lower lip. This tube reaches to the water faucet, which he turns on when he wants the "drier" to operate. Let us see how decreased air pressure makes this device possible. The stream of water from the faucet flows rapidly downward. Occasionally the water carries a few air particles down with it. After a short while, enough air has been carried away to reduce the pressure within the tube. Then, the normal air pressure, acting on the saliva in the mouth, pushes the fluid into the tube and toward the water stream.

A similar device is used by chemists as a filter pump. When the pump is attached to the funnel in which a liquid is being filtered, a decreased air pressure is created below the stem. Normal air pressure forces the liquid more rapidly through the pores of the filter.

If it were not for pumps, most of the useful work which air performs would be impossible. It is with pumps of one kind or another that air is compressed or reduced in pressure. Pumps are used in daily life in many ways They carry drinking water to the tank on the roof and they fill the automobile tires with air. They force water to put out a fire and they push illuminating gas into huge storage tanks. They fill the automobile tank with gasoline and they circulate the water which keeps the engine cool. They keep moving the liquid that freezes ice cubes in the refrigerator and they circulate the air in schools and in theaters.

The pump is an ancient invention and has been built in many forms. The first of these is the "lift pump." Here a cylinder containing a movable piston is connected with the supply of water by a pipe. Blocking the entrance from pipe to cylinder is a valve. The valve is like a hinged door which swings only upward, letting water up but not down. Within the piston is a second valve which acts in the same way. When the handle is operated, the piston moves up. This increases the volume under the piston and, consequently, the pressure is decreased. The normal air-pressure acting on the surface of the water in the well pushes the water up the pipe, past the valve—which opens—and into the cylinder. On the downstroke of the piston, the water oozes through the valve in the piston and enters the cylinder above the piston. The next upstroke lifts this water to the spout, and at the same time causes new water to enter the cylinder below the piston. The action goes on as long as the piston is worked up and down.

A lift pump is limited in certain ways. It does not provide a steady stream of liquid and it cannot raise water through a greater distance than 34 feet between the well-surface and the lower valve, for the normal air pressure can press with only enough force to maintain a water column of that height. A force pump overcomes these drawbacks.

The force pump also consists of a cylinder, piston, and pipe reaching down to the water supply. It also has a valve which lets water enter the cylinder and does not let it return. However, there is no valve in the piston, which is entirely solid. From the lower end of the cylinder a second pipe emerges and goes to an air chamber. The entrance to this chamber is blocked with a valve that lets water in, but not out. From the lower end of the air chamber, another pipe carries the water to a roof tank or to a hose.

During the upstroke, water enters the cylinder as in the lift pump. The downstroke which follows pushes the water into the air chamber. There the air is compressed. Each succeeding downstroke compresses this air still more. The valve on the air chamber keeps both the water and the compressed air within the chamber. When the main supply valve is opened, the air pressure forces water to the tank or out through the hose. The stream is a steady one, for the air in the chamber expands steadily. The height to which the water may be forced depends entirely upon how much the air is compressed; and that depends upon how hard and how long the piston is operated and upon the strength of the air chamber.

Although the two types of pumps described above are used chiefly for pumping water, the principle underlying their action is the same when applied to removing air from a vessel or to crowding more air into a given space. In an air exhaust pump, the pipe leading to the cylinder is attached to the vessel from which the air is to be drawn. During the upstroke, the air from the vessel rushes into the cylinder; and during the downstroke, this air is expelled into the room. Continued movement of the piston exhausts the air in the vessel. Good pumps can produce an almost perfect vacuum.

If, instead of expelling the air as described above, the air is forced to enter a tank, the device acts like an air-compressor pump. In this case, the air which is crowded into the tank comes from the room. The valve action in air pumps is the same as in water pumps, although air valves are more carefully fitted and adjusted.

But there are certain types of pumps, much used nowadays, which have neither pistons nor valves. Of these, we may mention the centrifugal (sĕn-trĭf'ū-găl) pump and the rotary pump.

The first of these consists of a wheel carrying curved blades. The wheel usually turns at a tremendous speed and sweeps into pipes the liquid or the gas that is being pumped. The action is much like that of an electric fan or of a propeller. The great value of the centrifugal pump is that it may be used to move liquids containing solids.

The second valveless and pistonless pump is known as a rotary pump. Here, gearlike wheels enmesh, rotating rather slowly. The device is especially useful for pumping heavy, sticky liquids, like molasses and tar.

Reading Unit No. 23

WHAT IS THE HEAVIEST THING IN THE WORLD?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The first balloon to fly above the earth, 1–467-68
A duck, a rooster, and a sheep, the first aviators, 1–468
The first men to fly, 1–468-69
Why does a block of wood float? 1–469
Archimedes' Law, 1–470-71
Why steel ships float, 1–471
The submarine, 1–471-72
The lightest and the heaviest substances, 1–473

Things to Think About

Is a heavy stone pushed up by the water in which it is immersed?
Why does a balloon float in the air?
How does the amount of water displaced by an object affect the lifting force that water exerts upon immersed objects?
How much water does a ship displace?

Picture Hunt

How is the buoyancy of floating and sinking objects determined? 1–470
How can you prove that an object weighing a pound loses weight in water? 1–469
How does a submarine raise and submerge itself? 1–472

Related Material

How have submarines affected civilization? 7–320, 326, 10–367
What kind of submarine did the great artist Leonardo da Vinci design? 11–151
What are the advantages of dirigibles for commercial aviation? 10–364
How are dirigibles constructed? 1–482
What were the famous clipper ships? 10–216, 223
What was the earliest known ship? 10–161
How do ships make use of wireless? 10–116, 121

Practical Applications

How can the weight of liquids be determined with the aid of a hydrometer? 1–474
How are the hulls of ships constructed? 1–471

Leisure-time Activities

PROJECT NO. 1: Make a boat model, 14–34.
PROJECT NO. 2: Show your friends that an object loses weight in water, 1–469.

How to find out if the King's crown was made of pure gold!—that was Archimedes' problem. He had noticed that a certain amount of water was pushed out of a brimming tub of water when he entered it. In the picture you see him immersing the King's crown in a large vessel so arranged that the water will overflow into another bowl. By catching and weighing the displaced water and comparing it with the weight of the crown in water, Archimedes solved his difficult problem. Our story will explain the whole matter to you.

WHAT IS *the* HEAVIEST THING *in the* WORLD?

And What Is the Lightest? And How Do We Measure the Weights of All Sorts of Things?

TO FLOAT and swim in water must have come easily and naturally to man. All about him he sees objects that bob up to the surface when they fall in. He sees creatures that make their homes in water and others that can, when occasion demands, jump in and swim. What brave soul it was who first dared to imitate animals by floating in a lake or stream, will never be known. At any rate, the art of moving about on water goes back to the earliest time of which there is record. Through trial and error and, in recent years, by means of scientific experiment, this art developed tremendously. To-day, transportation by water is an important and necessary business, free of most of the dangers and losses that beset the navigators of old.

On the other hand, the history of navigating the air presents quite a different picture. It has been very difficult for man to leave the solid earth. He lives in an ocean of air; but his feet are ever on the ground. True, he has many examples about him of insects and birds that fly; but he does not seriously attempt to imitate them because he has no wings. In fact, what little effort at imitation he made in the past only served to confirm his belief in the impossibility of rising from the ground. Not only does he lack wings, but his muscles are too weak to flap wings, if he had them. Man is not so strong as birds in proportion to his weight. It took a long time for the idea to be born that wings do not need to be flapped and that one can stay aloft by means which Nature, in all of her many experiments with plants and animals, has never employed.

Now what were these means, invented by man as an improvement on Nature herself? Briefly, it may be said that man learned why bodies float in water and applied this knowledge to make bodies float in air.

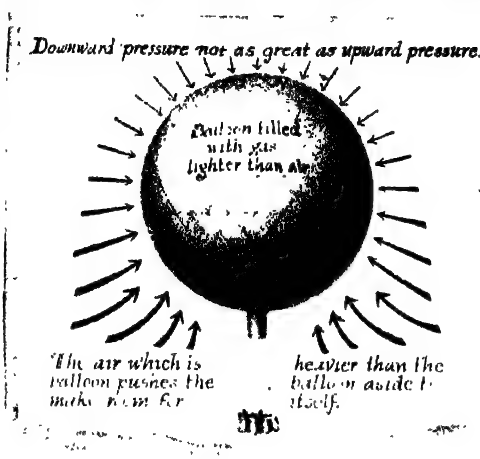
The first balloon that ever rose from the ground did so in the year 1783. It was a crude affair, sent up for amusement rather than for any serious purpose. The persons responsible were Stephen and Joseph Montgolfier (mōN'gôl'fyā'), two Frenchmen who owned a paper business. It had occured to

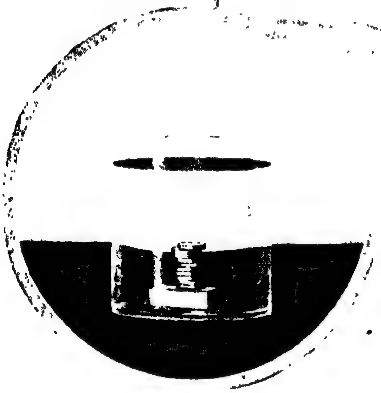
them that if "smoke" could be inclosed in a large paper bag, the bag might float like a cloud; for did not clouds seem to be masses of "smoke"?

Having plenty of paper with which to experiment, they constructed spherical bags open at the bottom. In order to fill them with smoke, they burned paper beneath the openings. This filled the paper balloons, and several of them actually floated to the ceiling. The brothers were astonished and delighted, and called in their friends to see the new toy. Had they realized that from these small beginnings would come the modern dirigible, and that 149 years later Professor Piccard (pē'kär') would use a balloon to explore the atmosphere more than ten miles above the earth's surface, they might have thought of their work as something more than an innocent recreation.

Friends urged the two brothers to float their balloons out in the open; and soon the two were sending bags up to heights of 70 feet. Success spurred them on. A balloon with a capacity of 600 cubic feet rose 700 feet. Another holding 2,300 cubic feet of "smoke" rose 1,000 feet. On June 5, 1783, they gave a public exhibition with an even larger bag; when it was released, it shot up to a height of 6,000 feet before it began to come down.

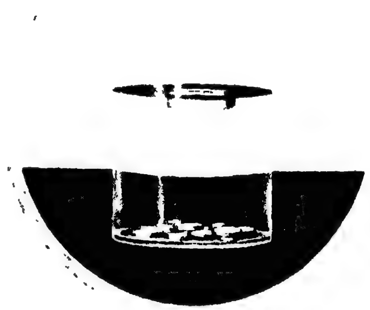
The news spread all over Europe. Kings and queens were interested and invited the Montgolfiers to build even larger bags. On September 19, 1783, a balloon which weighed 1,000 pounds and carried as passengers a duck, a rooster, and a sheep, reached a height of 1,500 feet. It landed two miles from the starting place without injuring the animals in the slightest. The time had come for man himself to climb into the basket for a pioneer trip in the ocean of air.





A block of wood is resting at the bottom of a jar of water. The water it displaces is pushing it upward; but the weight of the coins overcomes this push and holds the wood down.

The balloon rises because the weight of the air it displaces is greater than the weight of the balloon itself. When it reaches an elevation where the air is less dense, the displaced air will exactly equal the weight of the balloon. At this point the balloon comes to rest.

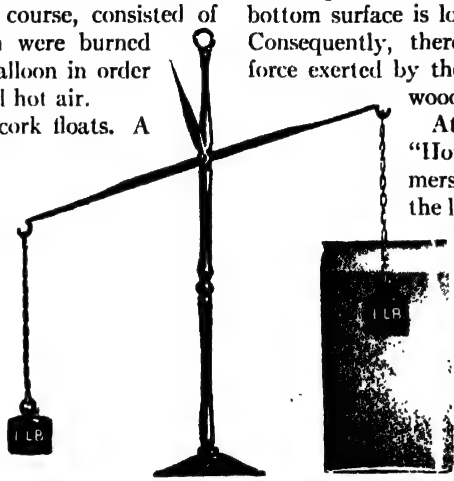


Take a pencil and slide off one of the coins in the pile shown at the left above. Then slide off another. If you continue this, the upward push of the water on the wood will soon overcome the weight of the remaining coins, with the result shown in the picture above.

Two persons volunteered to make the aërial voyage. They were the Marquis d'Arlandes (dår'lôNd') and Monsier des Rozier (dĕ rō'zyā'). Cheered by thousands of spectators, the balloon with its human cargo made the ascent on November 21, 1783. It rose to a height of 3,000 feet and

was carried along by the wind over the streets of Paris. After about twenty-five minutes of flight and a voyage of some two miles, it came to earth. Had they wished, the passengers could have gone three times as far, for two-thirds of their fuel still remained. The fuel, of course, consisted of paper and rags, which were burned underneath the paper balloon in order to fill it with smoke and hot air.

A stone sinks and a cork floats. A man falls to the ground, but a balloon rises in the air. If a satisfactory explanation can be found for the behavior of substances immersed in water, the same explanation will serve for bodies immersed in air. Let us consider this point in some detail.



First balance the scales with a one-pound weight attached to each arm of the scales. Then surround one of the weights with water, as shown in the picture. The balance is destroyed; for a body immersed in a liquid loses weight. The displaced liquid, in trying to return to the space it occupied, pushes the body upward.

Throw a block of wood into a jar of water. Immediately it floats to the top. Try to push it under and you find that you must exert a force. Weight it down with a few coins and it rests on the bottom. Remove one or two of the coins and the block lifts those remaining, as it rises to the top. Certainly the block itself has not the power to lift things. Then it must be the fact of its being in water that is responsible. But what has immersion in a liquid got to do with it? Just this: when the block is placed in the water, it must occupy some space. The water *and* the block cannot occupy the same space at the same time. So the block pushes the water aside in making room for itself. The water, in trying to get back to where it was at first, exerts a pressure upon every side of the block—left, right, front, back, top, and bottom.

How much is this pressure? That depends upon how far below the surface the block is pushed. But the pressure toward the left is exactly equal and opposite to the pressure toward the right. The two forces together serve only to squeeze the block somewhat. The same thing is true of the water pressures exerted on the other two sides. But the water pressure down upon the top surface is less than that exerted upward upon the bottom surface, since the bottom surface is lower down in the liquid. Consequently, there is an upward lifting force exerted by the water on the block of wood.

At this point one may ask, "How about a stone immersed in water? Does not the liquid exert a lifting force upon it? Why, then, does it sink?" The water *does* exert a lifting force on the stone and on any immersed object whatsoever; but in the case of a stone, this lifting force is not great enough to overcome the stone's weight. Stone is heavier than wood. But anyone who has lifted an anchor out of the water knows that it is easier to lift the anchor while it is still immersed. The lifting force of the water helps you. This help ceases when the anchor comes above the surface.

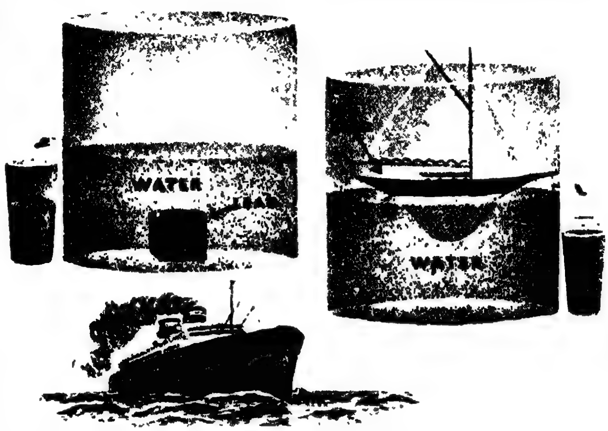
Why a Balloon Rises

Now let us consider a man and a balloon, both immersed in air. The man's body pushes the air aside in order to make room for itself. So does the balloon. The air, in trying to get back to where it was at first, presses in all directions upon the man and upon the balloon. For the same reason as was pointed out in the case of the block of wood immersed in water, the upward air pressure upon man and balloon is somewhat greater than the downward air pressure. So the air exerts a lifting force upon both the man and the balloon. In the case of the man this lifting force is less than his weight; so he remains on the ground, weighing slightly less than he would in a vacuum. In the case of the balloon, the lifting force is greater than

the balloon's weight; and so the balloon rises.

Archimedes (är'kĭ-mē'dēz) was a Greek philosopher living from about 287 to 212 B.C. In many ways he was a modern scientist, for he believed in experimentation and devoted a good part of his life to the discovery of truth by putting questions directly to nature. One of his great discoveries had to do with the lifting force that liquids exert upon bodies immersed in them. It happened in this way:

The King had received a gold crown as a gift; but he had reason to be suspicious of the quality of gold of which the crown was made. "Can you find out," he said to Archimedes, "whether this crown is made of pure gold? But do not destroy the crown or damage it in any way." For a long while Archimedes was puzzled as to what to do. Then, according to the story, an idea came to him while he was taking a bath. He noticed that when he stepped into a tub which was brimming, a certain amount of water was pushed out to make room for his body. Also, he noticed that the water lifted him with just enough force to enable him to float. When he weighed the water that was pushed out, he found it to be almost exactly the amount which his body weighed. That was interesting; for by weighing the displaced water, he could tell exactly how much was the uplifting force of the water. He tried a block of wood and found that if it pushed out one pound of water, then the entire block weighed one pound. In the case of a stone, he found that if the displaced water weighed one pound, then the stone weighed one pound less *in* the water than it did in the air. Each different kind of substance lost a different fraction of its weight when immersed. Iron lost about one-seventh of its weight when immersed; lead, about one-eleventh; copper, about one-ninth; and pure gold, about one-twentieth. Each of these substances, therefore, sank. Wood lost all of its weight and floated.



In the jar at the left a cube of solid lead is immersed in water. Note that it displaces an amount of water equal to itself in volume. In the second jar, the same piece of lead has been hammered into the shape of a boat. Now it floats and can carry, in addition, the sails and the rigging. The explanation is that it can now displace more water. In fact, the boat sinks to such a depth that the displaced water is equal in weight to the weight of the boat and all that it carries. The increased amount of displaced water is seen in the overflow jar at the right.

Then he tested the King's crown by weighing it in a jar brimming with water. He caught the displaced water and weighed it. He compared this weight with the weight of the crown in air and found that the fraction was *larger* than one-twentieth. Proudly, he announced to the King that the gift was not pure. The crown contained baser metals than gold.

Our readers may be interested to know that Archimedes was so excited when the idea came to him that he ran through the streets, shouting, "Eureka!" The word, in Greek, means "I have found it!" To this day we use the expression "Eureka!" when we have solved some knotty problem.

The Great Law of Archimedes

Of course Archimedes might well be pleased at serving his king; but the world is far more grateful to him than the King could be, for a law of science had been established—the Law of Archimedes. In simple words the law might be stated thus: The lifting force exerted by liquids and gases upon bodies immersed in them, is exactly equal to the weight of liquid or gas which these bodies displace.

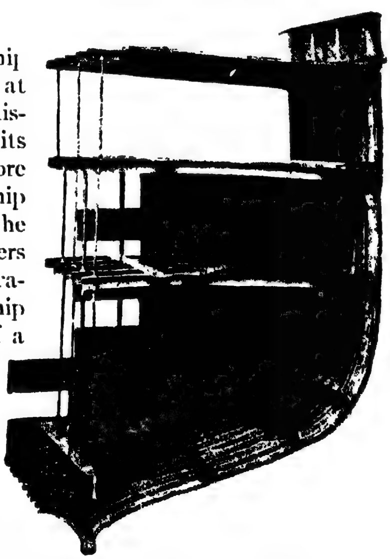
As a result of Archimedes' experiments,

we have a way of telling whether or not a body will sink or float. "Will this heavy steel ship sink?" you ask. That depends upon how much water it pushes aside. If it displaces 10,000 tons of water and it weighs 15,000 tons, it will surely sink. But how is it possible for steel to do anything except sink? Now of course it is true that a bar of steel will always sink. But if the steel is shaped so that it can displace more water than it displaces when it is a solid lump, then it may float. Most certainly it does not sink if it displaces an amount of water that weighs more than its own weight.

This steel ship, about to be launched, weighs thousands of tons; yet it will float, and will keep afloat a cargo of considerable weight. If the ship and its contents were to be rolled into a solid ball, it would undoubtedly sink, because it would not then displace so much water as before.

In fact, a floating ship sinks only to the depth at which the amount of displaced water is equal to its own weight. Load more cargo on a ship and the ship settles further down in the water. Perhaps our readers know that the carrying capacity, or "size," of a ship is referred to as being of a given number of "tons displacement."

When a diver wishes to sink to the river bottom, his shoes are weighted with lead; for the uplifting force upon his naked body is greater than its weight. Most human beings could never drown if they had presence of mind enough to float quietly. The uplifting force of water upon a swimmer is practically equal to the swimmer's weight. Of course, if he splashes excitedly about and takes water into his stomach and lungs, he increases his weight without increasing his displacement. He therefore sinks and perhaps drowns. Fat people find it easy to swim because they displace so much water in proportion to their weight.



This is a sectional view of a steel ship's hull. Notice the air spaces. If these were to be filled with water, we could then weigh the water and determine the displacement of the ship. By breaking up the space in the hull into numerous chambers, the safety of the ship is increased; for in case of an accident, not all the air chambers may be damaged. The chambers left intact may be large enough to keep the ship afloat.

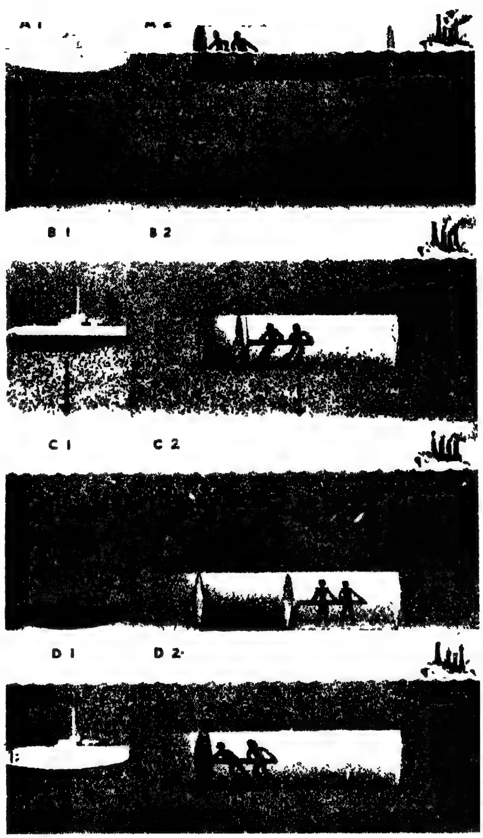
Submarines submerge by taking in more water. In this way they increase their weight without increasing their displacement. They rise by pumping out the water which they have taken in.

Airplanes certainly weigh more than the air which they displace. Were it not for the rapidly-moving propellers, the machines would drop like a stone. When the engine stalls in mid-air, the pilot must either glide to safety or else take to his parachute.

We have said that a submarine takes in water in order to submerge. In other words, it makes itself slightly heavier than the uplifting force due to its water displacement. However, once it begins to sink, it continues to sink until it reaches the bottom. In this it resembles an airplane the engine of which has stalled. But

like an airplane, it maintains a desired level by turning a propeller which drives it forward. Also like an airplane, it manipulates horizontal rudders, called elevators, by means of which the direction of its motion may be changed up or down.

People sometimes wonder if a ship that sinks in very deep water does not descend to a point somewhat higher than the bottom and stop there. They point to a balloon which sinks to a certain level in the air, where it remains poised and motionless. But the notion is wrong; bodies sinking in water sink all the way to the bottom. The reason for this difference between bodies in water and bodies in air is that water is practically incompressible, while air is very compressible indeed. Thus, a displaced cubic foot of water, near the surface, weighs about 62 pounds. A cubic foot of water at a point a mile beneath the surface, weighs practically the same. In the case of air, it is quite different. A cubic yard of air at a height of two miles weighs, perhaps, one-half pound; at a height of one mile a cubic yard may weigh one pound. So a 1,000-pound balloon at a height of two miles must displace 2,000 cubic yards of air in order to stay afloat. If its displacement is only 1,000 cubic yards, it sinks until a level is reached where the air weighs more. At a mile above the earth, 1,000 cubic yards of displaced air may weigh 1,000 pounds; and so the 1,000-pound balloon comes to rest and floats at that point.



Have you ever wondered what makes it possible for a submarine to sink and rise in the water? The principle is very simple; when the submarine wants to sink, it takes in water; and when it wants to rise, it lets the water out again. Our two little men in the tank will show you the principle of it—in a simple way, of course. A1 is a submarine afloat. Like the tank shown in A2, the submarine is empty of water and therefore is floating. At B1 the submarine has taken in water and is sinking; it is as if the two men in the tank (B2) had let in a little water. Of course they begin to sink. When they have let in still more water (C2), they go rapidly to the bottom, as the submarine has done on taking in more water (C1). In D2 the two men have shoved all the water from the tank and are rising; and also the submarine (D1), when it is emptied of the water it took in, is mounting to the surface.

A cork floats because it weighs less than the water which it would displace if immersed. In fact, it bobs up above the surface, submerged only to a depth at which the displaced water weighs as much as the cork weighs in air. Even a solid lump of iron can float—if it is placed in a dish of mercury; for the mercury displaced weighs as much as the lump of iron.

When water freezes, it expands; so ice weighs less than water. A gallon of water weighs about ten per cent more than an equal volume of ice. That is why icebergs float. As in the case with a cork in water or iron in mercury, an iceberg sinks to such a depth that it displaces an amount of water equal to the iceberg's entire weight. It is not often understood that eight-ninths of an iceberg is under water.

Smoke goes up the chimney because it is made up of minute particles floating in heated gases. The hot gases are lighter than air because the heat has expanded their volume. Since these gases displace an amount of air which weighs more than they weigh themselves, they are lifted upward in the usual way.

The Gases Used in Balloons

When the Montgolfier brothers filled their paper bags with smoke, they made use of these heated gases. Some years later, when the Montgolfier method of floating balloons seemed too dangerous, a search began for a gas which, even when cold, was lighter than air. With such a gas, man could rise higher and stay longer. The search led to the gas we call hydrogen (hī′drô-jĕn), which is the lightest substance in the world. Its weight is about one-fifteenth the weight of air. A hundred and fifty pounds of hydrogen gas would inflate a bag till it occupied about 1,000 cubic yards. Such a bag displaces 1,000 cubic yards of air, which, at sea level, might weigh 2,000 pounds. The uplifting force acting on the balloon would then be 2,000 pounds, which is more than enough to push up the bag, the 150 pounds of hydrogen, the basket, and the passenger. The balloon would rise until the air displaced weighed just the same as the hydrogen, the bag, and all that the bag carried.

When dirigibles were first constructed, they were filled with hydrogen; but hydrogen is inflammable, and many terrible accidents occurred. This resulted in a search for some other gas. Recently airships have been filled with the gas called helium, which is very light, though not so light as hydrogen. Helium is about one-seventh as heavy as air. Of course, when great heights are to be explored balloons are filled with hydrogen, as was the case when Professor Piccard made his ascent of more than ten miles.

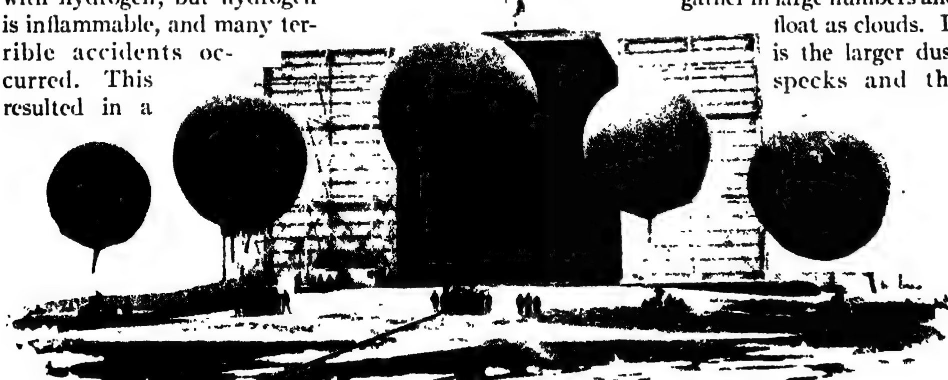
It is often said that no one can ever drown in Great Salt Lake or in the Dead Sea. As we know, these bodies of water are extremely salty; and salt water is heavier than fresh water. A person immersed in salt water does not need to sink so far as in fresh water before he displaces his own weight of the liquid. So it is easy to swim and easy to float in Great Salt Lake and in the Red Sea.

A Test for Fresh Eggs

We know a man who tests the freshness of eggs with a jar of salt water. If the egg sinks quickly, it is fresh; if it sinks slowly, or if it floats, it is bad. The test is based upon the fact that as an egg grows stale, it generates gases and loses some of its substance through the pores of the shell. Becoming lighter and yet retaining its volume, the egg tends to float. This is a simple test to use at home.

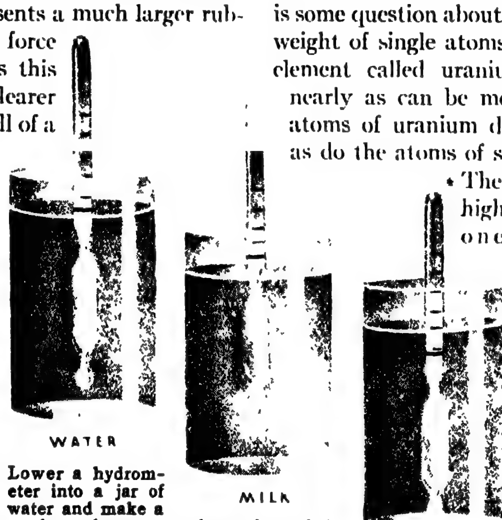
A particle of dust is usually a solid piece of matter, heavier than air. It is very small, of course; but it also displaces very little air. Why does it not sink to the ground? The same question may be asked of liquid water particles that gather in large numbers and float as clouds. It is the larger dust specks and the

The picture below shows the opening of a balloon race. All five balloons are released from the hangar at the same time. Of course the wind is the driving force for all of them. If all the balloons are required to be of the same total weight, to be of the same volume, and to use the same gas inside the bag, it will be only balloon construction and luck that will determine the winner.



rain drops that fall to earth. The only satisfactory explanation which can be given is that these heavy particles *do* sink. Yet as they start their fall, the force of friction retards their movement to such an extent that they stay suspended for a very long time. Why does not this happen to rain drops also? Because the surface of such a drop is small in proportion to its weight. The same drop broken into a thousand smaller particles presents a much larger rubbing surface for the force of friction. Perhaps this idea can be made clearer by considering the fall of a parachute. As the parachute drops from an airplane, before opening, it behaves like any other falling body; but when it spreads out and presents its huge surface to the passing air, the great umbrella settles slowly to the ground.

In a sense, it is quite useless to say that wood is lighter than iron or that iron is lighter than wood; because one must first know how large a piece of wood is in question and how large a piece of iron. Of course a thumb tack made of iron is lighter than a chair made of wood. But if we compare equal volumes of wood and iron, then it is fair to say that wood is lighter than iron. In order to avoid any misunderstanding, the man of science compares the weight of any substance with the weight of an equal volume of water. Thus, a cubic inch of iron is about seven times heavier than a cubic inch of water. In the same way, copper is nine times as heavy as water; and lead eleven times as heavy. Gold is nearly twenty times as heavy as water; and so on with other metals. "Specific gravity" is the number of times any given substance is heavier than an equal volume of water.



Lower a hydrometer into a jar of water and make a mark on the stem at the surface of the water. Call this "1." Since milk is a slightly heavier liquid than water, the hydrometer will not sink so deep in milk. The specific gravity of milk is about 1.03. If lowered into gasoline, the hydrometer will sink deeper than it does in water, for gasoline is lighter than water. The specific gravity of gasoline is about 0.68.

If the weight of the entire earth, with everything that it contains, were compared with the weight of an equal sphere made entirely of pure water, we should find that the earth is five and one-half times heavier. That is to say, the specific gravity of the earth as a whole is about 5.5.

We know that hydrogen is the lightest thing on earth. What is the heaviest? There is some question about this. Considering the weight of single atoms, the prize goes to an element called uranium (ū-rā'nĭ-ŭm). As nearly as can be measured, however, the atoms of uranium do not pack as closely as do the atoms of some other substances. The substance with the highest specific gravity is one called osmium (ŏs'mĭ-ŭm).

If a liquid is heavy, a body immersed in it will not sink very deep. If the liquid is light, the body will sink deeper or even go to the bottom. Hence, the depth to which a floating body sinks in a given liquid is a measure of its density. Now suppose a weighted glass tube is allowed to float in water. Let the point to which it sinks be marked "1.000." That indicates that the specific gravity of water is 1.000. The same weighted tube floated in glycerin will bob up higher, for glycerin is a heavier liquid. Mark the new point "1.300," which is the specific gravity of glycerin. In carbona, the tube bobs up still higher, to a point which may be marked "1.600."

In liquids lighter than water, the tube sinks lower. In alcohol, the point to which it sinks is marked "0.800." In gasoline, the point is "0.68." Thus the weighted tube becomes an instrument for measuring the specific gravities of liquids. It is called a hydrometer (hī-drŏm'ē-tēr).

PHYSICS

Reading Unit
No. 24

WHY A HOT THING IS BIGGER THAN A COLD ONE

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Keeping the home at a constant temperature, 1–476
Automatic hot-water heating, 1–477
The gas refrigerator, 1-477
Why railroad tracks have spaces between the ends of rail sections, 1-478
Heating systems, 1-480
Cooling water and its volume, 1–482-83
Winds, 1-483

Things to Think About

Why may railroad trains be wrecked if spaces are not left between the rails in the track?
How does a thermostat control temperature?
Why do sidewalks sometimes crack and buckle?
What makes hot water flow through pipes without the aid of pumps?

Picture Hunt

How does a chimney do its work? 1–481
How does expansion and contraction affect the construction of airships? 1–482
How does the air valve on a steam radiator operate? 1–479

Related Material

How do blacksmiths remove and replace iron wheel rims? 1 470
How is a building air-conditioned? 1-393, 400, 10 519
How does the air thermometer measure changes in temperature? 1-389-91
How is temperature regulated? 10–385
How does a hot-water heating system operate? 1–398
How is the expansion and contraction of cables on suspension bridges taken into account in the building of the bridge? 1–478
How do expansion and contraction produce air currents? 1–222-25

Practical Applications

How is the air in cold radiators removed in order to allow for the entrance of steam? 1-479
How is the contraction of cooling metals useful in building construction? 1-479

Leisure-time Activities

PROJECT NO. 1: Show your friends that water expands when heated, 1 481-82.

PROJECT NO. 2: Make a thermostat from a strip of iron and a strip of copper, 1-480.

Our boy is so intent upon getting his ball away from the dog that he is forgetting to watch where he is going. Perhaps he does not realize that the best-laid cement walk may develop cracks and bumps, as this walk has done. When the heat of the summer sun beats down upon the sidewalk, the concrete expands. If the ruled spaces between "boxes" is too small to accommodate this expansion, the concrete must buckle and crack.

Photo by H. A. Strong Roberts

WHY *a* HOT THING IS BIGGER *than a* COLD ONE

And How We Use This Fact of Nature in Making Many a Machine

WHEN Fred invited Bob to visit his new home, he knew that what would interest his friend most would be the many new scientific appliances with which the house was fitted. And so, at the first opportunity, Fred took his guest in tow for a tour from cellar to attic.

"Do you know," said he, "that three of the most important conveniences in this place depend upon a very simple principle of science? Perhaps you can guess what this principle is if I show you these three features of our house.

"In the first place, no room in the house can get colder than we want it to be. I like my room cool; so I set this little pointer on the wall at 64 degrees. Only when the temperature drops below 64 does steam begin to warm up the room. When 64 degrees is reached the radiator is shut off. It never fails. In the room next door, my sister keeps the temperature always at 70 degrees. If no heat is needed anywhere in the house, the oil stops flowing into the furnace burner. Just as soon as any room upstairs grows a bit colder than the temperature for which the occupant has set the pointer, oil begins to flow to the burner; and in a jiffy the fire is making lots of steam.

"The second great convenience in our house is also a form of heat. We can have all the hot water we want, at any time of the day or night we want it. The surprising thing is that this constant supply costs us less in fuel than the awkward arrangement we had in the old house. We never burn fuel for hot water except when we turn on the "hot" faucet. Doing that causes a great

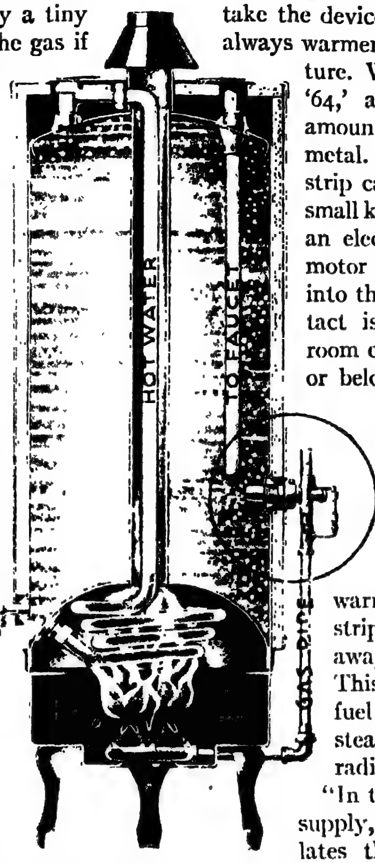
rush of gas in the water heater. As soon as the faucet is shut off, the gas stops flowing and the flame dies down. Only a tiny light remains, ready to ignite the gas if someone upstairs should open a faucet for hot water.

"The third convenience I want to show you is the gas refrigerator. This too works automatically. When the air inside the box gets warmer than 40 degrees, a rush of gas to the flame below soon starts a cooling device inside the box. It is certainly a wonderful thing to see a burning gas flame make water freeze into ice.

"Now, what do you suppose is the mechanism which operates all three of these conveniences? Let me show you. Come down to my laboratory in the cellar where I have arranged an interesting experiment."

Fred's experiment was very simple. First he showed Bob a metal ball fastened to a rod embedded at one end in a wooden handle. The ball fitted nicely through a metal ring which was similarly fitted with a handle. Then, Fred heated the ball in a candle flame. When he tried to push the ball through the ring, the ball stuck tight. Evidently heating the ball had expanded it somewhat. In order to make the ring pass over the hot ball, Fred now heated the ring. But plunging the ring into a jar of water caused it to shrink again. Only when the ball too was cooled in water, did it pass through the ring again.

"Why, I know what this shows," said Bob. "We learned about this in school. Heating causes a piece of metal to expand and cooling causes it to contract. But what has all this to do with the things you showed me? I didn't see any ball in them."

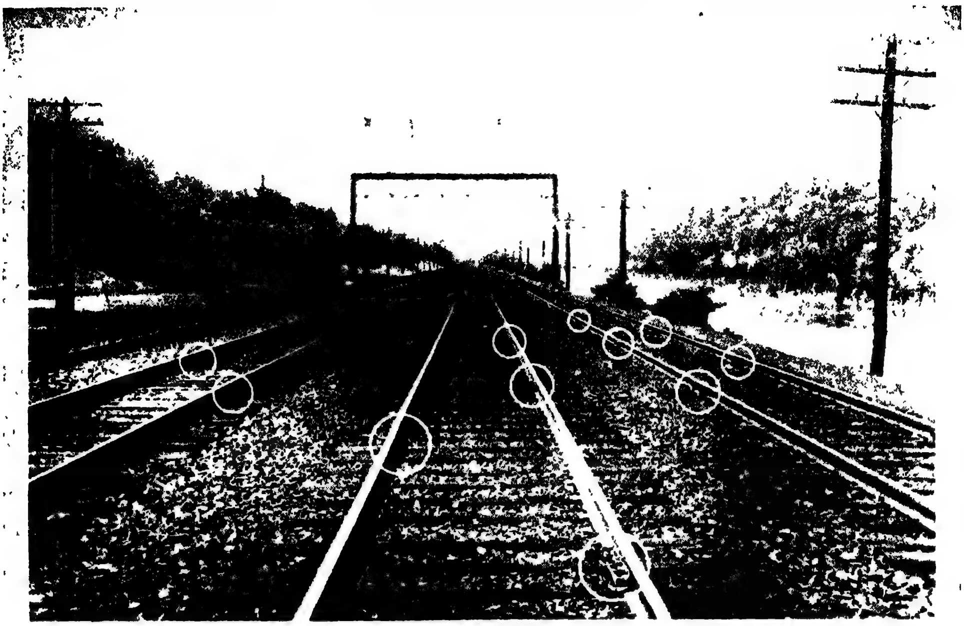


From the diagram above you may learn how a gas water-heater works. First, the gas flame heats the water in the coil. The hot water rises to the top of the tank, and as cold water is drawn off, gradually fills the tank down to the level of the pipe leading to the faucet. Of course as hot water is drawn out, fresh cold water is let into the coil at the bottom of the tank. Within the black circle in the picture is the automatic device which shuts off the gas when the water reaches a certain high temperature. It turns on the gas when the water cools to a certain temperature; so that there is always hot water without a waste of gas. This delicate device is a kind of thermostat; as our article explains, it makes use of the fact that metals expand when they are heated and contract when they are cooled.

"Everything," was the reply. "Let us take the device which keeps the room always warmer than a certain temperature. When I set the pointer at '64,' a screw puts a certain amount of tension on a strip of metal. You will notice that the strip can make contact with a small knob. If contact is made, an electric current flows to a motor below and fuel is forced into the furnace. But the contact is not made unless the room cools down to 64 degrees or below. The tension of the screw keeps the metal strip away from the knob. But the metal shrinks when it cools and in doing so bends over to touch the knob. Then the room is warmed; but soon the metal strip expands and breaks away from the contact knob. This stops the motor, the fuel supply is shut off and steam stops coming into the radiators.

"In the case of the hot water supply, a similar device regulates the flow of gas to the heater. Next to the pipe which leads to the 'hot' faucet there is a rod. When the faucet is turned on, cold water flows and the rod is cooled. Cooling makes the rod shrink. A catch is then released which turns on a full flow of gas to the heater. It does not take long for the flame to warm the heating coil; so that hot water soon rises to the faucet. When the faucet is shut off, the hot water accumulates and warms the rod, which expands. The expanding rod shuts off the gas.

"In the refrigerator, too, a piece of metal expands and shrinks as the temperature changes. When the inside of the



Straight and smooth this railroad track stretches away into the distance, and over its firm rails the trains will speed at ninety miles an hour. But that is possible only because at every point where two rails meet a little space has been left between them, to allow for the amount that the rails will expand under the summer sun. If it were not for those little gaps, indicated by the circles in the picture above, the crowded rails would buckle and wreck the first train that passed. It is those little breaks in the rails that cause the regular "click" of the wheels and the tiny jolts when a train is in motion.

box grows warmer than 40 degrees, the expansion causes more gas to flow to the burner below. The hotter the flame below, the colder it gets inside the box. Soon it gets cold enough, and then the shrinking piece of metal shuts off the full flow of gas."

The story is told of an unfortunate railroad accident in which a twisted rail threw a train off the track. It seems that new rails had been laid on a rather cold day. The different sections, each about twenty feet long, stretched end to end for about a quarter of a mile. Several months after the work was completed, on a warm summer day, a train was sent out to make a trial run over the new rails. Everything went well for a time; so the engineer put on full steam and grew quite unconcerned about the track ahead. The locomotive sped on at sixty miles an hour toward the fatal quarter mile of new rails. There the steel had expanded in the warmth of the summer sun. Since the twenty-foot lengths were touching end to end, there was no space in which the rails could expand. Hence they had buckled, twisting upward and sidewise in several places, and tearing the bolts from the ties. Without warning the wheels slipped from the track. The train lurched to one side and toppled with a crash over an embankment.

Of course the cause of the accident was the failure of the workmen to realize that solids expand as they absorb heat. Nowadays such errors are carefully checked before any train is sent over a newly laid track.

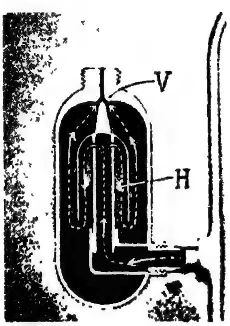
The beautiful span across the Hudson River—the famous George Washington Memorial Bridge—hangs from four huge cables. Each cable contains 61 strands and each strand is made up of 434 steel wires, each about the thickness of a lead pencil. In the cables alone there are more than 100,000 miles of wire. In winter this wire shrinks; in summer it expands. As the length increases, the roadway sags; as it shortens, the roadway rises. Of course all

this is hardly seen by the ordinary observer; yet the stresses and strains caused by expansion and contraction are very real indeed. In some bridges the cables pass over rollers at the top of the towers. In others the towers themselves are so built that they can sway at the top to accomodate the changing length of the cables. A bridge that does not take proper account of expansion under heat is a very unsafe structure.

Engineers who design skyscrapers must also reckon with expansion caused by heat. The steel girders are the skeleton upon which the entire building is hung. Wherever two beams join, a space must be left between ends. Furthermore, the hole through which the fastening bolt is inserted is often slotted to permit the beam to slide for a little distance. It is a terrible thing to think of what might happen to such a structure as the Empire State Building if its skeleton of steel were to be fastened too rigidly.

Home owners are often disturbed by the appearance of fine, irregular cracks in the concrete walks about the house. Even when the greatest care is taken in mixing the cement and in laying the concrete, these ugly lines may develop. They tend to grow worse with time, soon calling for expensive repairs or replacement. Again, the chief culprit is expansion due to heat; for concrete, like any other solid, must expand as it absorbs heat and must contract as it loses heat. One reason why sidewalks are usually lined off in boxes is that space is thereby provided to allow for expansion.

On our public highways one can see rather wide cracks at regular intervals separating the different sections of concrete road. Even then, sufficient allowance for expansion is not made; for after some two or three years every road shows irregular cracks in many places. These are filled with pitch and tar soon after they are formed.



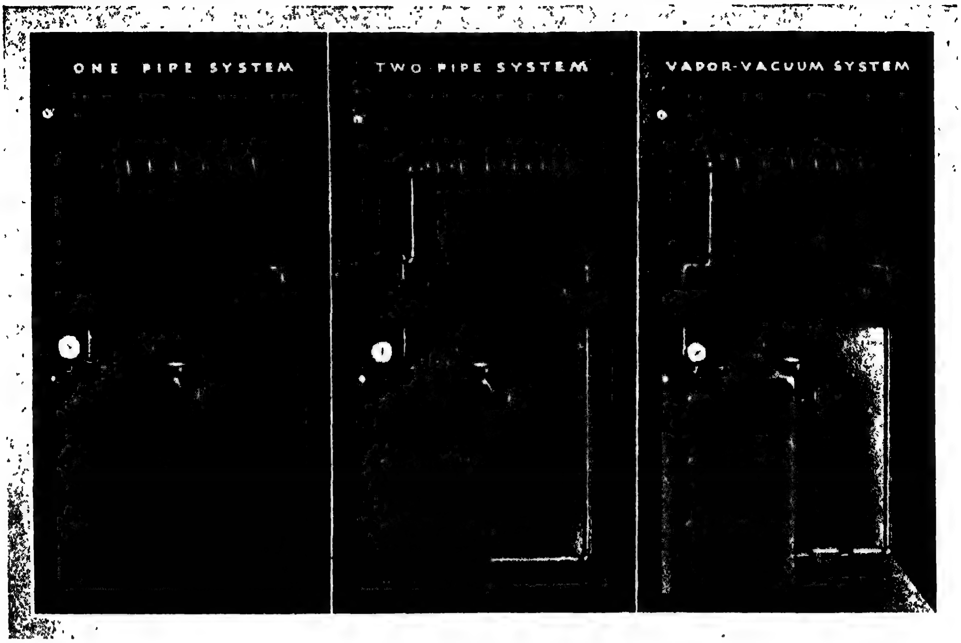
This diagram shows the small dome-shaped valve on a steam radiator. In order that the steam may enter the radiator the air must first be pushed out. Now the incoming steam does push out the air through V; but when the steam begins to leave the radiator, it heats the rod H. The rod expands and shuts off the opening at V. In this way the valve serves to let out the air but to keep the steam in.

Very hot tea can never be poured into a thick tumbler or cup without danger of cracking the container. Yet a thinner tumbler can withstand the heat better. The reason for this will be clear if we consider again the effects of expansion from heat. The inside surface of the thick-walled tumbler gets hot first. The heat penetrates to the outer surface very slowly, since glass is a poor conductor of heat. Thus the inside wall tends to expand, while the outside wall does not. The resulting strain usually causes the glass to crack. If the wall is thin, the outer and inner surfaces get warm practically together and they both expand together. Then there is no strain.

Most of us have been fascinated by a riveting gang at work putting up a steel structure. One man keeps a furnace going, where steel rivets are made red-hot. When they are hot enough, he grabs a rivet in a pair of tongs and throws it to another workman who catches it cleverly in a pail. The rivet is inserted into the matched holes of two steel plates, and the compressed-air hammer soon squeezes a head or knob at both ends of the rivet. When the rivet cools, its length shrinks, drawing the steel plates firmly together. Thus, the force of contraction due to cooling holds together large units of the skeleton of a bridge or skyscraper. Between these larger units, of course, space is provided for expansion. This has already been explained above.

Why a Wheel Rim Was Heated

This method of fastening steel plates reminds one of a similar process, not very often seen now, yet very interesting as an application of expansion due to heat. In the days when horse-drawn wagons were more common than they are to-day, the blacksmith was often required to remove an iron rim from a wooden wheel. To remove a rim without breaking the wood, he ap-

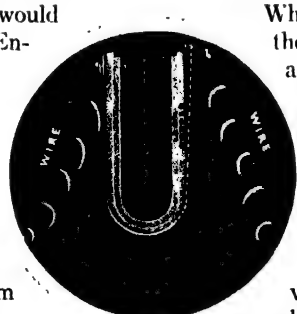


In a one-pipe steam-heating system the same pipe brings steam to the radiator and takes the water—formed when the steam condenses—back to the boiler. In a two-pipe system, separate pipes are provided, one for bringing the steam and one for returning the water.

In a vapor-vacuum system, there are two pipes, and a suction pump in the return line. The pump helps draw out the water and any back pressure of steam that there may be in the radiator. This allows new steam to enter the radiator under safe pressure.

plied heat carefully to the metal. The rim expanded and was then easily forced off. To put it on, the blacksmith would again heat the metal hoop. Enlarged by the heat, the rim would fit fairly easily over the wheel. As it cooled, it shrank, forcing the spokes tightly into the hub.

Every steam radiator has a little dome-shaped valve attached to the outside at one end. Its purpose is different from that of the main steam valve, which is usually operated by hand and which controls the entrance of steam from the pipe leading to the boiler below. Our attention is called to the dome-shaped valve whenever it hisses and sputters, or when the superintendent comes up to see why the radiator is cold in spite of the fact that there is plenty of steam in the boiler. He usually tinkers with the little valve and tells us that the radiator is "air-locked."



This picture of an electrical thermostat shows how the bending of a compound bar —note the U-shaped double strip of iron and copper— may make an electrical contact that will open the steam valve leading to the radiators. The thermostat may be set to operate at any desired temperature.

When steam first comes up from the boiler, the radiator is filled with air. Since two things cannot occupy the same space at the same time, the air must be pushed out if the steam is to enter. The pressure of the steam is usually sufficient to do this, and the air leaves by way of an opening in the dome valve. But soon the steam too begins to pour out of this opening, threatening to fill the room with vapor. Then the heat expands a little rod in the valve which, in stretching, causes the opening to shut. Sometimes a piece of dirt lodges in the opening and the air cannot get out. Then the radiator is "air-locked" and remains cold. Again, the rod may not be properly adjusted. In that case, not only

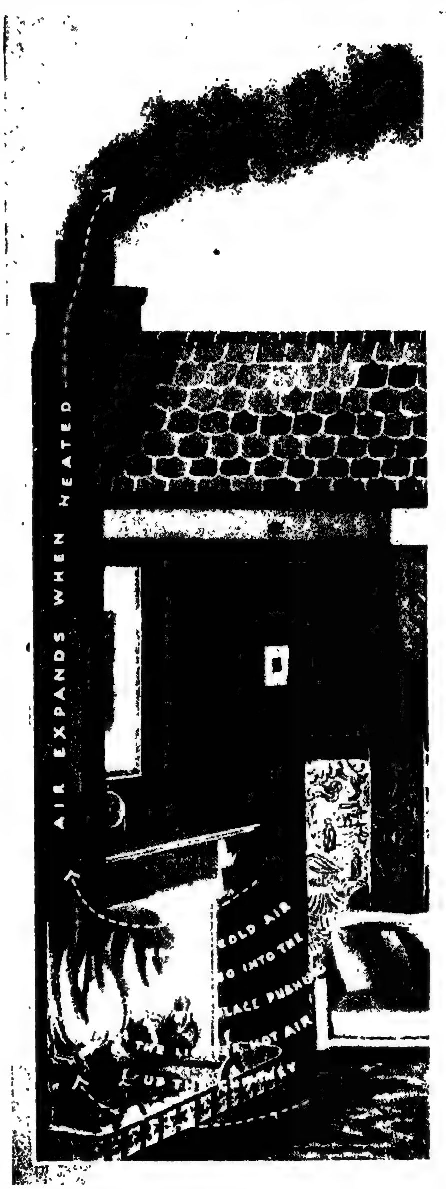
air but steam may shoot out from the valve. The superintendent repairs the valve by setting the rod at just the point where a slight expansion due to heat will shut the opening. The valve must let the air out but keep the steam in.

In very large buildings the dome-shaped valve is usually absent, since a special pump is provided to draw out the air and to help the steam to enter the radiators.

The fact that different substances expand differently is the basis of several interesting devices. If a strip of iron is riveted to a strip of copper and both are heated equally, one will try to expand more than the other. However, since the rivets prevent one from sliding along the other, the combined bar will bend. The device is called a "compound bar." You may recall the explanation Fred gave his friend Bob when he told how it was that his house was kept always warmer than a certain temperature. The little pointer on the wall, set for "64," operated a metal strip which bent when it grew cold. This metal strip is a compound bar, bending one way or the other as it grows warmer or colder.

When heated, copper expands more than iron, and iron expands more than glass. Below is a list of common substances, arranged in the order of rate of expansion. You will note that hard rubber expands most and a substance called "invar," which is an alloy of nickel and steel, expands least.

Hard rubber
Oak wood (across fiber)
Frozen mercury
Lead
Tin
Zinc
Aluminum
Silver
Cast brass
Bronze
Gun metal
Copper
Monel metal
Gold
Steel
Nickel
Marble
Wrought iron
Brick
Platinum
Cast iron
Granite
Glass
Cement and Concrete
Graphite
Carbon
Oak wood (parallel to fiber)
Porcelain
Diamond
Invar (nickel steel)



If you will look at this diagram you will understand clearly why the smoke goes up the chimney. If the chimney were taller, there would be a still longer column of air in it to expand as it grew hot. This would result in a still greater difference in pressure between the air in the room and the air in the chimney. The greater this difference, the stronger is the convection current of air which rushes upward and the faster, therefore, does the fire burn.

Here is an experiment you might like to try. Fill an empty milk bottle *exactly* full of ice-cold water. Then pour the water into a pot and heat

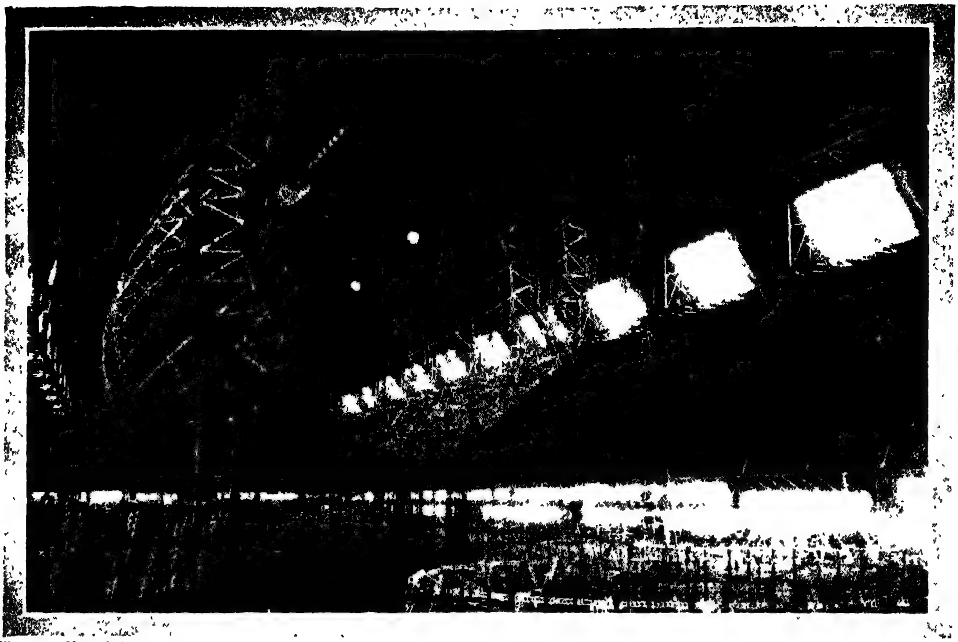


Photo by United States Navy

The bones of a giant dirigible are here being joined together with the greatest care, for on the strength of its metal skeleton the safety of the craft will largely depend. Pains must be taken to see that the contraction of the metal in the cold of high altitudes and its expansion on a hot day in the hangar do not cause the airships' ribs to buckle and thus bring on some terrible accident.

it over a gas flame. Do not wait until the water boils; but when it is fairly hot, remove the pot from the flame. Pour the water back into the bottle. There will be more than enough to fill the bottle. Where did the extra water come from? Of course there is no extra water. The water has expanded with the heat which was added. If you let the water in the bottle get cold, you will find that it shrinks just enough to leave room for the rest in the pot. Other liquids behave like water in this respect; all liquids absorbing heat expand, and those losing heat contract.

How Hot-Water Heating Is Possible

In a mercury or kerosene thermometer, this fact is put to good use. The liquid in the bulb expands as the room gets warmer and shrinks as it gets cooler. The rise and fall of the liquid level in the stem of the thermometer indicates the temperature of the room.

If it were not for the expansion of liquids as heat is added, boiling a kettle of water would be difficult, if not impossible. What happens is that the layer of water in contact with the bottom of the kettle gets hot first. It therefore expands. Because it expands, it grows less dense than the water above it, and floats to the top. Another layer of water is soon heated and that too floats to the top. In time the entire amount of water is heated. Otherwise, only the layer in contact with the bottom would boil, leaving the rest of the water cold.

Bearing all this in mind, one can understand why water at the surface of lakes and oceans is warmer than at the bottom; and why the water in a kitchen hot-water tank always rises to the top. In fact, this tendency of hot water to rise makes possible the heating of a house by the circulation of hot water instead of steam through the radiator pipes.

What Happens When Water Is Cooled

As water is cooled, it contracts. The colder it gets, the more it shrinks in volume. But only up to a certain limit! The limit is reached at about 39° Fahrenheit, which is

seven degrees warmer than freezing water. When water is cooled below 39 degrees, it begins to expand again—so rapidly that by the time it freezes, the ice occupies about ten per cent more space than did the water from which it was frozen. That is why ice floats. If water continued to contract, ice would be denser than water and would therefore sink to the bottom.

It is most fortunate for the world of plants and animals that water behaves in this manner. If this were not so, every stream, every lake, and every ocean would freeze from the bottom up instead of from the top down. In time this would result in solidly frozen lakes and oceans; for the summer heat could hardly penetrate more than a few feet of water. What would happen? For one thing, all ocean life would cease; and with it an important source of food for mankind. But an even more vital result would be the reduction of the amount of moisture in the air. There would be less surface water to evaporate. As a result, rain would finally cease to fall and plants would all die. In this way life depends upon the strange behavior of water in expanding rather than contracting after a temperature of 39 degrees is reached.

Why the Montgolfier Balloon Rose

The first balloon that ever rose from the surface of the earth did so because a gas expanded when it was heated. The Montgolfier brothers were the first makers of balloons. The only way they knew of causing their paper bags to float was to build a fire underneath the open ends of the bags. The heat quickly expanded the air inside and the bags swelled out. In this way, the balloon displaced a great deal of cold air. The cold air, because of its greater density, was heavier than the combined weight of the paper bag and the warm, expanded air which it contained. And so the bag was pushed upward.

It is easy to notice how warm air rises. One can feel an upward current of air by bending over a radiator. A pin wheel held over a radiator will be turned rapidly by the rising of the air. This upward flow is entirely due to the fact that warm, expanded air is less dense than the colder air which surrounds it. A room is heated throughout by a radiator in one far corner, because the radiator starts air flowing. As the warm air next the radiator expands and rises, colder air moves in to take its place. In time all the air in the room has passed the radiator and has absorbed some of its heat.

How Winds Start

On a larger scale, but in the same way, winds are started in the air outdoors. A land area strongly heated by the sun takes the place of the radiator. At the seashore the breeze usually blows in from the ocean during the day, since the land heats up more quickly in the sunshine than does the water. Thus the expanded air rises from the land and the colder air over the water flows in to take its place. At night the surface water of the ocean is usually warmer than the land, and a breeze from land to sea springs up.

Of course air that is cooled contracts. In a refrigerator the air around the ice or the cooling coil is constantly losing heat. So it shrinks in volume, grows more dense, and sinks. Warmer air takes its place. Soon a current of air is established which becomes colder and colder. The air at the bottom of the refrigerator is usually the coldest.

A great scientist once made a careful study of the rate of contraction and expansion of gases. He discovered that if the pressure of a gas remains the same, cooling it one degree Centigrade causes it to shrink $\frac{1}{273}$ of its volume Heating it one degree causes an expansion of the same amount. These facts led to a law of science, which may be stated as follows: At a constant pressure, the volume of a gas is always proportional to its temperature. The temperature, in this case, is the "absolute" temperature, which is the ordinary temperature plus 273. In another story that has to do with all this we shall learn more about the measurement of temperatures.

Reading Unit No. 1

WHAT A MAGNET CAN DO

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How long have magnets been known? 1–485
What do magnets attract? 1–486
Kinds of magnets, 1-486-87
Making magnets, 1–487
Destroying magnets, 1–487-88
The magnetic compass, 1–488-89
The earth's magnetism, 1–488-89
Electromagnets, 1–489-91

Things to Think About

Why are many magnets shaped like a "U" or a horseshoe?
Why does a compass point north?
Explain what happens electrically when you push the button of a doorbell.
How can the strength of a magnet be regulated?

Picture Hunt

How does a magnet behave when the pole of another magnet is brought near it? 1–487
Explain why an electric bell rings, 1–490

Related Material

In which countries are the earth's magnetic poles located? 10–456, 13–508
How does the sun affect the earth's magnetism? 1–115
How is a ship made to follow the compass automatically? 1–291, 10–457
How is the compass used in path-finding? 14–562-64
What is a radio compass? 10–121
How may iron affect a compass? 10–456
How is the magnet used in telegraphy? 10 95, 97-98
How are magnets used in telephones? 1 518-20

Practical Applications

How does a compass depend upon a magnet for its action?
How are large loads of iron moved? 1–489
How do magnets ring our bells? 1-490

Leisure-time Activities

PROJECT NO. 1: Make a compass, 1–488, 10–455.

PROJECT NO. 2: Make an electromagnet, 1–486.

Summary Statement

Magnets are made of iron and steel. They attract chiefly iron and steel and, to a slight extent, several other substances. The compass consists of a freely suspended magnet whose poles are attracted by the magnetic poles of the earth.

The rubbing has torn away a great many electrons from the wool. They are now on the surface of the pen, which is therefore negatively charged. A charged body exerts a force of electrical attraction upon objects near it.

This boy has rubbed his fountain pen with a piece of wool. Now he finds that the pen can attract and hold up pieces of paper. The pen seems to act like a magnet, although, unlike a magnet, it can attract any light object, and not iron alone. In the circle you see what is believed to be the reason for this.

WHAT *a* MAGNET CAN DO

From a Mere Toy, the Little Horseshoe with Its Strange Power Has Grown into One of the Mighty Forces on Which Civilization Now Rests

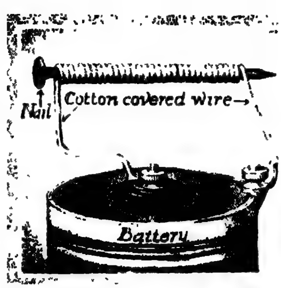
MANY years ago a shepherd in the far-off land of Asia Minor was peacefully tending his flock. All was quiet as he rested on a convenient rock overlooking the countryside. He was idly playing with his metal-tipped staff, tapping here and there, when suddenly his curiosity was aroused. That stick of his was behaving strangely. Now and again it seemed harder to lift, after the end had touched certain parts of the rock. What was holding it down?

At last the shepherd began to examine the rock, but he could see nothing unusual. Certainly the rock was not sticky to his touch. Rubbing his hand over the piece of iron with which the rod was tipped, he found it neither wet nor unusual in any other way. The whole thing was so surprising that he broke off a piece of the rock to show to his friends at home.

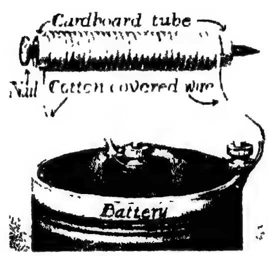
According to the story, this shepherd's name was Magnes. His friends named the strange rock after him, calling it a "magnet." Of course it is hard to say whether there is any truth in the story. Those who have looked into the matter tell us that magnets of this kind were known thousands of years before the time of Magnes. The ancient Chinese, they say, used certain pieces of stone as compasses; and in the writings of the Greeks and Hebrews references are made to "lodestones," which are pieces of stone that always point in the same direction when suspended freely by a string. The word "lodestone" really means "leading stone"; for it can lead a person to find his way when he is lost.

Whatever be the true story of the discovery that a certain kind of stone is attractive to a piece of iron, we may imagine the wonder and fascination felt by the first

human being to observe the fact. If such a person could have looked into the future and seen the wonderful inventions that have flowed from the study of magnets, he would have been still more thrilled with his discovery. In a sense, the magnet is the ancestor of the radio and of television. Indeed, there is little in the material structure of modern civilization which does not depend upon magnets and magnetism. If we lost our knowledge of them, life as we live it to-day would be seriously disturbed, if not stopped altogether. Let us therefore learn as much as we can about the way in which magnets act.

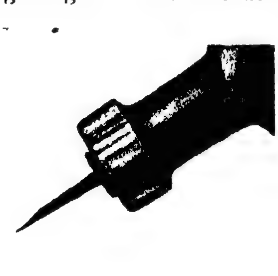


This is the simplest way to make an electromagnet. Wind about fifty turns of thin cotton-covered copper wire around an iron nail and connect the ends of the wire with the terminals of a dry cell. While the current is flowing the nail is a rather strong magnet. The moment the circuit is broken, the magnetism is lost. In making such a magnet, do not keep the wires connected for too long a time, for the heat produced by the current may burn off the cotton covering, especially when the cell is brand-new.



Around a paper mailing tube wind several hundred feet of cotton-covered wire. Then connect the ends of the wire with the terminals of a dry cell. This is a convenient way of making magnets. A nail inserted in the tube will become a strong temporary magnet, as it did in the experiment described above. A nail file or a pair of scissors inserted in the tube will become a permanent magnet.

A boy once lost a penny when it slipped from his hand and fell through a grating in the sidewalk. He could still see the coin, only two feet down on a ledge, but he could not reach it. He tried to fish it out with a stick, but could not lift it in that way. Then he ran home for the little red horseshoe toy which his father had recently brought him, and which could lift nails and tacks. Tying a string to the magnet, he let it down until it touched the coin, but there was no attraction. Try as he would, the penny would not stick to the magnet. Finally he gave up and went home. That night he told his father about it. "Why," said his father, "don't you know what a penny is made of?"



The head of this hammer is permanently magnetized, and can hold a tack in position. If you have ever tried to hammer a small tack into a spot that was hard to get at, you will understand how convenient a tool such a hammer can be.

"It contains copper, I suppose," replied the boy.

"Yes, and other metals too; but no iron."

"What difference does that make?"

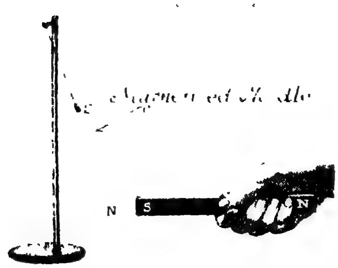
"All the difference in the world. You see, magnets attract chiefly iron."

So the boy saw that he had been trying to do an impossible thing.

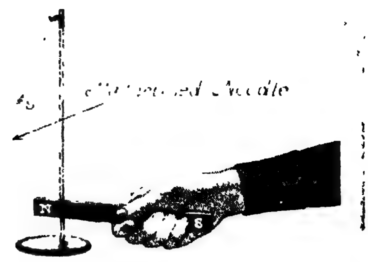
In scientific laboratories it is possible to show that magnets can slightly attract certain metals besides iron, such as nickel, aluminum, chromium, and platinum. It has been shown also that most substances, other than iron and those mentioned above, are slightly repelled by a magnet. But for practical purposes we may assume that magnetism is an attraction for iron and certain iron compounds, such as steel.

Since we are to make a study of how magnets are used in daily life, let us first say something about the different kinds of magnets. In the first place, we can separate the magnets that are found in nature from those that man himself makes. Natural magnets are usually pieces of lodestone. The chemist calls this "magnetite," which is an important iron ore. It looks like a piece of red-brown rock. Artificial magnets are made of iron or steel in ways which we shall soon describe.

We also distinguish magnets by their shape. Artificial magnets may have the



An ordinary needle has been strongly magnetized and suspended from a support by a thin thread. The point of the needle is the "north" end. When the south pole of a bar magnet is brought near the needle point, the point swings over toward the magnet.



When the bar magnet is reversed and its "north" end is brought near the needle's point, the point moves away, as is shown in the picture. The first law of magnetism is that unlike poles attract each other and like poles repel each other.

shape either of a bar or of a horseshoe. Sometimes they are made in other shapes for special purposes.

Magnets may be further classified as permanent or temporary. A soft iron nail may be made to attract another nail if a steel bar magnet is held near it, but the nail ceases to be a magnet as soon as the steel magnet is removed. On the other hand, if sewing needles are used instead of nails, they will retain some of their magnetism for a long time. Thus we may say that very hard iron or steel can be permanently magnetized, while soft iron can be magnetized only temporarily.

One of the most interesting kinds of temporary magnet is the electromagnet. Anybody can make one by winding a short length of insulated wire around a nail or a bolt and then connecting the ends of the coil with a dry cell. So long as the current is flowing through the wire coil, the iron core is a magnet. The moment the current is cut off, magnetic attraction ceases. Of course if the core of such a magnet is a piece of steel, it will retain its magnetism for a time even after the current stops flowing.

The best way to make strong magnets is to use a wire coil of many turns and a large flow of electric current. By winding such a coil around a paper mailing tube and connecting it with several dry cells, good magnets may be made. With the coil in position and the current flowing, needles, bars of steel, nail files, and similar things that are put into the tube will be magnets when taken out. If a horseshoe magnet is desired, one can first magnetize a steel bar by putting it into the coil and then bending it to the desired shape. If the bar is already bent into a horseshoe, it is necessary to magnetize each arm separately. But one thing must be remembered. Before magnetizing the second arm of the horseshoe, change the direction of current flow in the coil. Otherwise both arms will be north poles, or both will be south poles. This is usually not desirable.

When you put away your horseshoe magnet, be sure to attach a piece of soft iron to the poles, as shown above. This will prevent the magnet from losing some of its strength. The piece of iron is called the "keeper."

In the days before we knew about electric current, magnets were made in another way. They were magnetized by "induction." If a permanent or natural magnet is brought near a piece of steel, the latter becomes a magnet. Thus a steel needle when rubbed properly against a piece of lodestone, a bar magnet, or a horseshoe magnet, becomes itself a magnet. We might imagine that the rubbing would result in weakening the original magnet, but it does not do so. Hundreds of magnets can be made in this way from a single strong one.

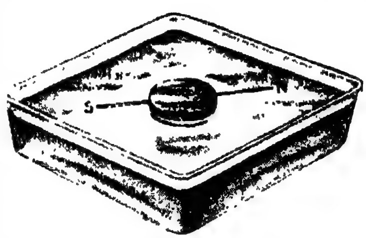
The easiest way to destroy a magnet is to

heat it red-hot. Scientists are not entirely agreed as to why this should be so; but many think that the increased heat energy makes the molecules dance so fast that they collide furiously with one another and become disarranged.

What the "Keeper" Is For

Sometimes a permanent horseshoe magnet grows weaker and weaker as it is allowed to lie around unused. To prevent this a piece of iron called a "keeper" is placed across its ends. In the case of bar magnets, the magnetized bars should be stored in pairs in such a way that the north pole of one touches the south pole of the other.

We have referred several times to "north poles" and "south poles" of magnets. What are the poles? Examining a magnet, we can find no difference between its middle and its ends; but if it is immersed in a pile of iron filings, we see an interesting thing take place. The filings tend to cling more to the ends than to the middle of the magnet. In fact, there is no attraction at all in the middle. The points at the ends, where the greatest number of filings hold fast, are called the "poles." When a bar magnet is bent into a horseshoe, it is because we wish to bring the poles nearer to each other. In this way the attractive force is made greater.



First, magnetize an ordinary needle by stroking it properly on a bar magnet. Then stick it through a flat cork. When the cork is floated in a dish of water, the needle will swing around till it points north and south, just as the needle does in a compass.

Stick a magnetized sewing needle through a flat cork and float it in a dish of water. Be sure the dish is not made of iron. After a while the needle will stop moving. Note the direction in which it points. Disturb its position a bit, and it will come back; for it must point always in the same direction. That direction is nearly north and south. And the same end of the needle always points south.

If a bar magnet is freely suspended from a silk thread, the bar insists upon pointing north and south when it comes to rest. It will do the same thing whenever it is pivoted on any point that allows it to turn freely.

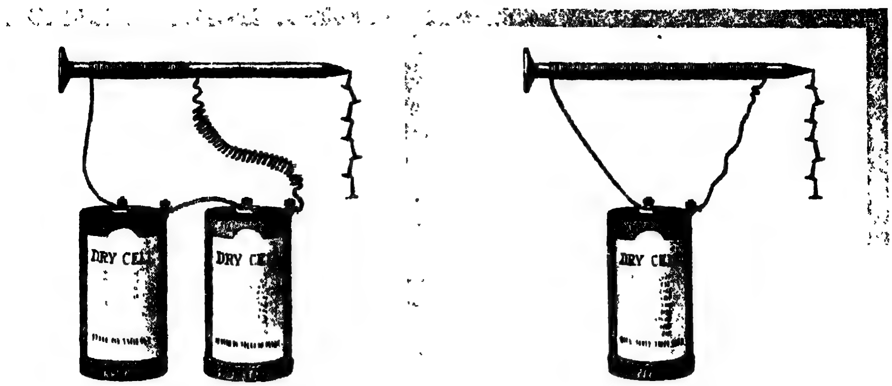
This behavior of a magnet is what makes the compass possible. A compass is nothing more than a delicately pivoted and magnetic needle, inclosed in a glass-covered case.

What happens when two compass needles are brought very close together? Anyone who has tried it knows that they both cease to read true; that is, they no longer point north and south. Instead, they point toward each other. And the north-pointing end of one is toward the south-pointing end of the other. Moving one compass around the other causes the needle ends to follow each other around. It is impossible to keep the two south ends together or the two north ends, for these ends push each other away.

Although man has known about magnets for thousands of years, it is only about two hundred years since we found out much about the reason for the way they behave. We now believe that the earth itself is a huge magnet. Therefore it must have poles; and therefore it must have an effect upon any magnet on its surface. If a freely suspended compass needle is held always in a certain direction, it must be because the poles of the earth magnet are attracting the poles of the compass magnet. Since unlike poles attract each other, the north-pointing end of a compass needle must, in reality, be a south pole; and the south-pointing one a north pole. But to save confusion we have all agreed to make the north-pointing end of a magnet "north" and the other end "south."

Why the Earth Acts like a Magnet

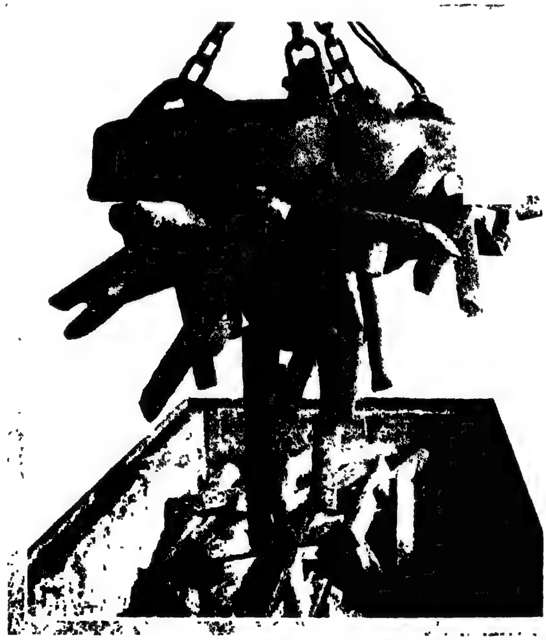
Perhaps you have been wondering why the earth should act like a huge magnet. This is something of a mystery, although many interesting theories have been proposed to explain it. Some say that most of the earth's interior is composed of metallic iron and that it is hardly strange if our planet acts like a magnet. But what caused the huge mass of iron to become magnetized?



The strength of an electromagnet depends upon two things: the number of turns of the wire around it and the amount of current flowing through the wire. Each electromagnet above is strong enough to hold seven iron tacks. The magnet at the left is supplied by two dry cells; but the number of turns of wire around the iron nail is half the number around the nail in the magnet at the right. Thus, one magnet is supplied with twice the current supplied to the other, but the second has twice the number of turns.

The answer to this question is not easy to find. Scientists point out that the upper regions of the earth's atmosphere contain many particles charged with electricity. These electric charges are being swept round and round as the earth rotates. Thus an electric current is always flowing around the outside of our planet. We might compare this with the current flowing through a coil of wire wrapped around an iron core. We have already learned that this is the best way of making a magnet. Hence, say many scientists, the earth, which is mostly iron, becomes a magnet.

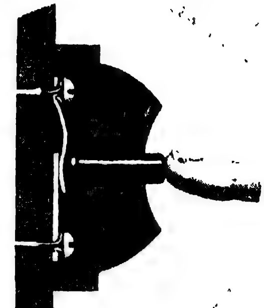
Whether or not the explanation is correct, there is no denying the magnetic action of the earth. Its magnetic poles have been located from time to time, and mariners since the day of Columbus have steered their ships with the aid of a compass. But the earth's magnetic poles are not in the same places as are its geographic poles, which are the ends of the axis around which our planet spins like a top. Worse than that, the magnetic poles change their position slightly from sunrise to sunset and from one season to another. In addition, the positions of the poles seem to be affected by the number and activity of sun spots on the surface of the sun. Occasionally tremendous magnetic storms occur, of which



This is one way of loading and unloading bars of pig iron. Each bar is held by the powerful electromagnet suspended from the hoisting crane. Note the two wires—at the upper right—which bring the electric current that activates the magnet.

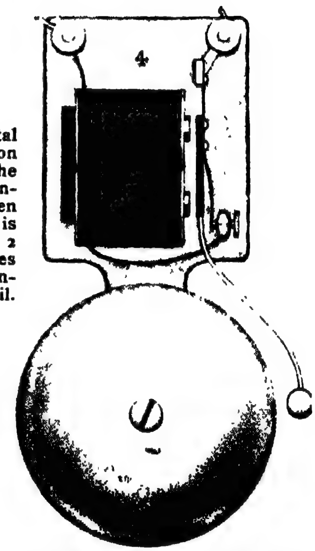
1

The pictures on this page will show you what it is that makes an electric bell ring. Before the boy in Fig. 1 pushes the button, the bell is silent, for no current is passing through the wires connecting the push button with the battery and with the bell.



2

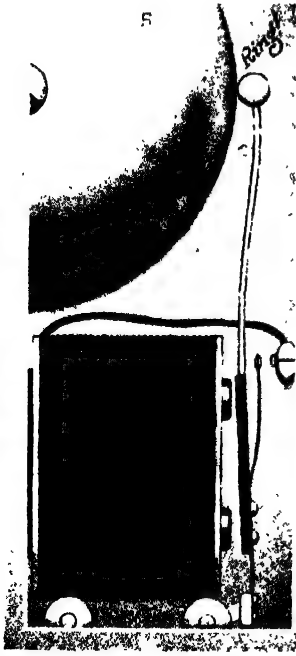
3



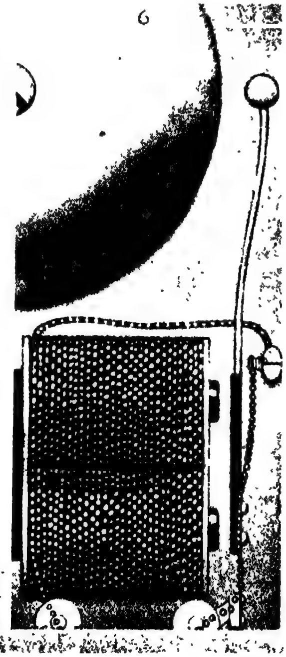
4

When our boy presses the button, he brings two pieces of metal into contact. One of them—the strip against which the button rests in Fig. 2—is connected by a wire with a battery (3). The second piece of metal—the straight, lower strip in Fig. 2—is connected with a wire that is coiled around a metal core and then connected with the battery. This coil, which is beside the bell, is shown in Fig. 4. Now when the boy presses the button in Fig. 2 and brings the two pieces of metal into contact beneath it, he closes an electrical circuit between the battery and the coil of wire. Instantly electricity begins to flow from the battery through the coil.

5



6



As soon as an electrical current begins to flow through the wire coil around the metal core, the core becomes magnetized. When this happens, the metal hammer that strikes the bell is drawn toward the magnetized core—as shown in Fig. 5—and its end strikes the bell. But when the hammer is drawn toward the magnet, the circuit through the coiled wire is broken. This means that the metal core is no longer magnetized. So the hammer can then be drawn back by a spring to its original position. Then the circuit is closed again, the electricity once more begins to flow through the coil, and the metal core is again magnetized. Again it attracts the hammer, and the whole process is repeated. The thing takes place so rapidly that the circuit is opened and closed several times in a second.

most of us are unaware. Yet captains of ships are greatly disturbed by them; for the storms disturb all compass calculations. Many of the magnetic changes in the earth take place regularly, and allowance can be made for them. Some, however, come suddenly. For that reason governments maintain magnetic charting expeditions which keep track of the changing positions of the earth's magnetic poles.

How to Make an Electromagnet

So much of the modern use of electricity depends upon the action of electromagnets that it will pay us to learn as much as possible about them. The best way of doing this is to make a few electromagnets in the manner suggested in a former paragraph. All one needs is a spool of insulated wire, an iron core upon which to wind it, and a few dry cells. In general, an electromagnet acts like a bar magnet; and if the core is bent into a horseshoe, the electromagnet behaves like any other horseshoe magnet. The attraction is concentrated at the ends, or poles; the middle shows no attraction at all.

Unlike a bar magnet, the electromagnet is a temporary affair, since its action depends on a continuous flow of electric current. This is a great convenience, for the attraction may be started or stopped in an instant, by the mere closing or opening of a switch. Thus huge magnetic derricks can lift tons of iron, swing them over a truck, and drop them in. While in the air, the iron is held fast by large electromagnets.

Regulating the Strength of an Electromagnet

Another convenience of this type of magnet is the ease with which its strength may be increased or decreased. Usually this is affected by a change in the amount of current. There are two additional methods, however, for weakening and strengthening an electromagnet. One is to change the number of turns in the coil of wire— the more turns, the greater the strength. The other is to change the nature of the core of the coil. A soft iron core gives the greatest magnetic strength. On the other hand, an air core results in low magnetic strength.

Electromagnets have become so useful in doing the world's work that we should all remember the name of the scientist who discovered how to make them. His name was Hans Christian Oersted (ûr'stĕth), and he was a professor of science in Denmark. One day in the year 1822 Oersted was lecturing to a class about the action of a magnetic needle. Near at hand was a wire through which a current was flowing. Every time he closed the current switch, he noticed that the needle moved. Further experiment led him to the discovery that electricity flowing through a wire produces magnetic effects. It was a happy thought which urged him to coil the wire and thus concentrate the magnetic attraction. Other men of science soon followed his idea. In America, Joseph Henry must be remembered for his pioneer work with electromagnets. In 1831 he made a coil so large that it lifted 3,500 pounds of iron when a large flow of electricity passed through the wire. The coil itself weighed only 100 pounds.

What Happens When You Push the Button

Almost every day of our lives we have reason to push a button in order to ring a bell. Most of us are so well used to this that we seldom think of the interesting thing that takes place. Pushing the button closes an electrical circuit which sets up a flow of current. The current passes through a coil of wire wound round an iron core, causing a magnetic attraction. A piece of iron is then pulled over, and with it a hammer which strikes a gong. No sooner does the gong sound than the circuit is broken by the very motion of the piece of iron. Immediately the flow of current ceases and of course the electromagnet loses all its strength. But than a spring pulls back the piece of iron and the hammer attached to it. As the iron strip returns, contact is again made, the current flows once more, and the electromagnet becomes active again, so that another stroke of the gong is achieved. The entire action repeats itself so long as your finger keeps pushing the button; the ringing of the bell is the result.

ELECTRICITY

Reading Unit
No. 2

THE SECRETS OF THE ELECTRIC CELL

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Who was the first man to study electricity? 1–494
Static electricity, 1–495
The first electric current, 1–495-96
The first battery, 1–496
The storage battery, 1-498
Electricity from chemicals, 1–498-99
Atoms, protons, and electrons, 1–498-500
The dry cell, 1–499-500

Things to Think About

Why did the legs of the frog used in Galvani's experiment jump about?
How does the dry cell give us electric current?
How did Benjamin Franklin prove that lightning was electricity?
How is static electricity produced?

Picture Hunt

What happens in a battery? 1–497
What does a storage battery contain? 1–498
What apparatus did Galvani use in his famous experiment? 1–496

Related Material

How is the storage battery used to light the gasoline mixture in the cylinder of an auto? 10–285
How is a submarine driven while it is under water? 10–310
How is electricity generated by muscles? 2–331
How are batteries used in the telephone? 10–110
How are batteries used in telegraphy? 10-95-99
What is all matter made of? 1–284
How are icebergs detected with the aid of electricity? 1–64

Practical Applications

How is pure copper made to-day? 1–500
How may muscles be tested? 1–495-96

Leisure-time Activities

PROJECT NO. 1: Make an electric cell, 1–497-500.
PROJECT NO. 2: Repeat Galvani's experiment showing that two pieces of different metals can cause frogs' legs to move, 1–496.

Summary Statement

An electric current is a movement of electrons. All matter is composed of electrons.

Photo Copyright by Detroit Publishing Co

Before Benjamin Franklin performed this famous kite experiment, few people suspected that lightning was really a tremendous flow of electricity from cloud to cloud or from a cloud to the earth. Franklin proved that fact. This simple though somewhat dangerous experiment started scientists on the path that finally brought them to their present understanding of the marvels of electricity and the nature of matter.

The SECRETS *of the* ELECTRIC CELL

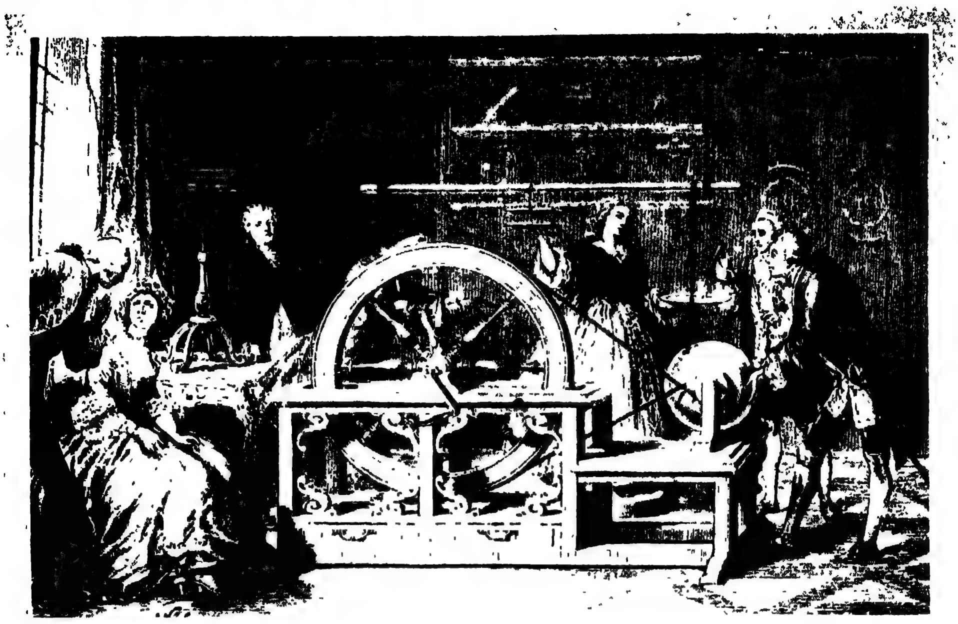
Here Is Part of the Story That Tells How the Heroes of Science Captured the Vast Forces of Electricity

IN THIS story we are going to talk about that marvelous form of energy which we call electricity. If we are to take the word of the modern scientists, everything in the entire universe is composed of electricity. The chair we sit in, the table at which we read, the book in our hands, the clothing we wear, the air we breathe, the food we eat—even our very bodies—are all made up of particles of electrical energy.

So important and basic a force merits our most careful attention. The fact that electricity has always been, and is yet, a great puzzle to mankind should not deter us from inquiring into its ways of behavior. Electricity is a challenge to our curiosity and understanding. On the one hand, we live in an age when the most difficult, the most complex, the most marvelous, and the most useful work is being done with the aid of electrical energy. On the other hand, we are still as far as ever from a really satisfactory answer to the question, "What is electricity?"

From a preceding story, in which we were talking about magnets, our readers will recall that there is no better way of making magnets than by sending a current of electricity through a coil of wire wound around a piece of iron. At that time we told the reader he could procure this current from a dry cell. But what is there in a dry cell that makes a current of electricity?

Perhaps as good a way as any to begin the



Otto von Guericke, a German scientist of the seventeenth century, devised a machine for rubbing two substances against each other so as to generate static electricity. In the picture above, you see the Englishman Francis Hawksbee performing some interesting electrical experiments with Guericke's machine.

study of electricity is to try to understand what goes on inside an electric cell. We cannot promise to make every part of the action fully clear, because no one in the whole world understands it completely. But we can tell the story of how scientists learned to make a cell and to use it, and what they think about it to-day, after many years of struggle with its mysteries. One of the strangest facts about science is that we can control and use forces in thousands of ways, even when we do not know the real nature of the forces themselves.

The First Man to Study Electricity

So far as records show, a great Greek philosopher, Thales (thā'lēz) of Miletus (mī-lē'tŭs), was the first man to study the subject of electricity, about twenty-six hundred years ago. Even before him men had observed the fact that when amber is rubbed against cloth or fur, small, light objects are attracted to the amber. But no one thought much about this until Thales announced his conclusion that the attractive power was due to a soul or spirit dwelling inside the amber. The Greek word for amber is "elektron"; and "electricity" is derived from this word

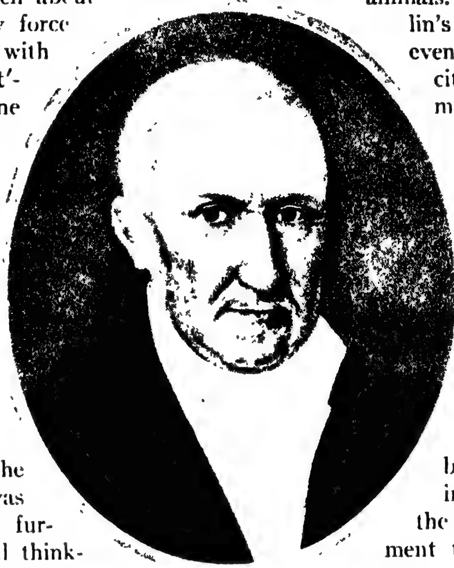
Early Experiments in Electricity

Then the entire subject seems to have been forgotten. Not until the beginning of the seventeenth century do we hear about it again. William Gilbert, physician to Queen Elizabeth, was a great experimenter, much interested in magnets. Without connecting magnetism with electricity, he showed that other substances than amber can also be excited by rubbing, and be thus made to attract light objects. He was especially interested in rubbing glass with silk. Some years later Otto von Guericke (fôn gā'rĭ-kē) made a machine which could rub sulphur and cloth together when a crank was turned. This enabled him not only to show attraction on a large scale, but to produce what he called "a hissing noise and gleaming light." Other experimenters carried on the work, and soon the electric spark

and the shock became more important than the mere attraction of rubbed bodies for paper and wisps of cotton.

Gradually facts about this kind of electricity accumulated. By the middle of the eighteenth century, the work of many men had made the subject a fascinating one, but no one understood much about the nature of the new force.

The sparks obtained with a rubbing, or static (stăt'ĭk), electricity machine made many experimenters think of tiny flashes of lightning. It is no wonder, therefore, that Benjamin Franklin planned his famous kite experiment. By sending up a kite in a storm he succeeded in getting a lightning discharge through the wet string. In this way he showed that lightning was really electricity. His further experimenting and thinking gave rise to a theory of electricity in which the strange force is regarded as a fluid—a weightless fluid—which passes from a place of high electric pressure to one of low pressure. For the first time scientists began to speak of two kinds of electricity: positive and negative. The former was the kind made when glass is rubbed with silk; the later, the kind obtained when amber or hard rubber is rubbed against fur. Always, said Franklin, electricity flows from positive to negative.



This is Alessandro Volta, the Italian scientist who was the first experimenter to make a chemical cell that generated a flow of electrons. After him has been named the "volt," which is a measuring unit for electrical pressure.

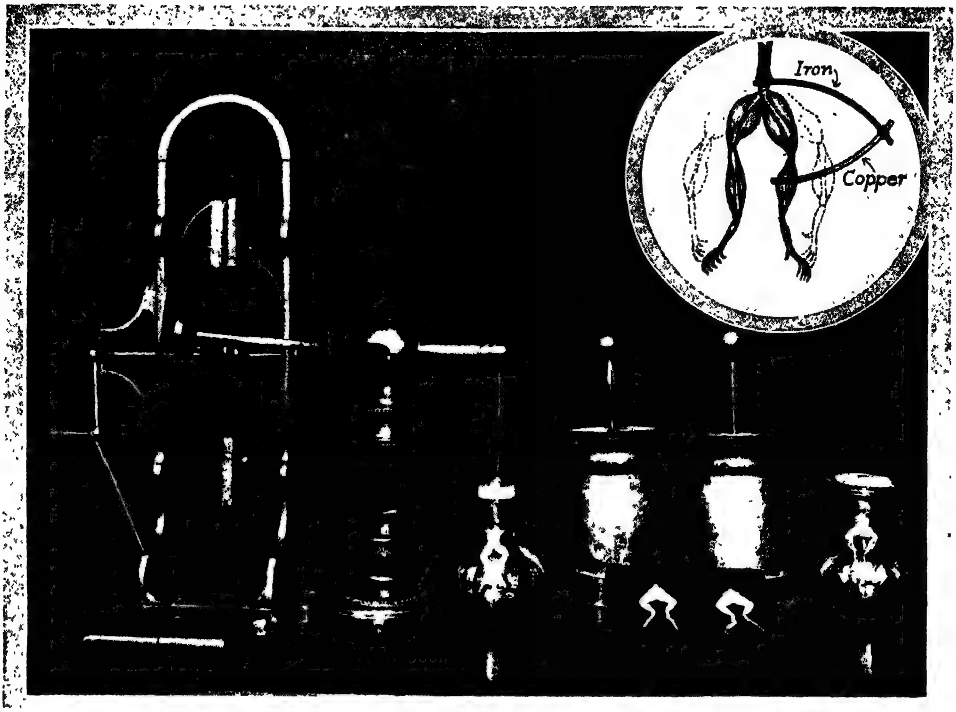
Galvani's Great Discovery

Very often in the history of science a lucky accident changes the whole course of events. We must not think that scientific development is a matter of chance, for apparently such accidents happen only to careful experimenters and good thinkers. Yet it is true that the modern age of electricity would probably have been delayed if a certain Italian scientist had not happened to hang some dissected frogs on an iron fence.

Luigi Galvani (lwē'jē gäl-vä'nē), the scientist in question, was interested in the action of a static electricity machine on the nerves and muscles of frogs and other animals. He had heard of Franklin's experiment and was even bringing down electricity from lightning to the muscles of skinned frogs' legs. By connecting one end of a leg with a stretched aërial wire and the other end with the ground, he found that the muscles twitched during a storm. While in the midst of these experiments, he or his assistant prepared some frogs and hung them by copper hooks to the iron balcony rail outside the window. To his astonishment the legs were convulsed every time they touched the iron rail while hanging from the copper hooks. No static machine or lightning seemed necessary. At first Galvani thought the effect was due to the condition of the atmosphere during a storm; but when the same thing happened during fair weather, he concluded that the real cause was the copper and iron touching the muscle or the nerve.

Galvani realized that he had made a great discovery. He had found a new way of obtaining electrical effects. But his explanations were very involved and, as we know to-day, inaccurate.

A better explanation was soon proposed by another great Italian scientist—the man whose memory we honor every time we speak of electrical voltage (vōl'tāj). Alessandro Volta (ä'lĕs-sän'drō vōl'tä) had been fascinated by the "galvanized" frogs, as they were called. He saw that three things were necessary to produce the effect: copper,



This is the apparatus used by Galvani to make the frogs' legs jump. The machine at the left generates electricity by friction. In the circle you see how he later discovered that the two different metals embedded in the tissue of the legs generated an electric pressure which caused the legs to jump.

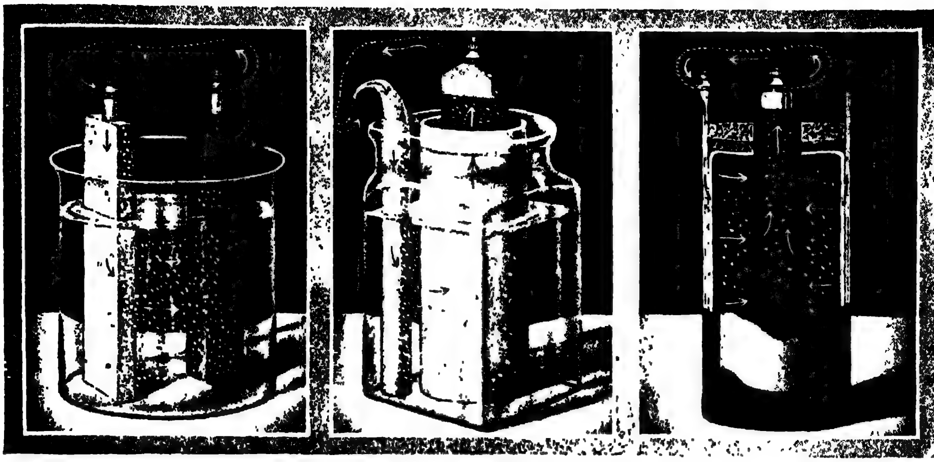
iron, and the fluid in the muscular tissue of the frog's leg. He made a brilliant guess. It seemed to him that the metals and the fluid were undergoing a chemical action. Thus was born the notion that chemical action can produce an electric force.

How the Voltaic Cell Was Made

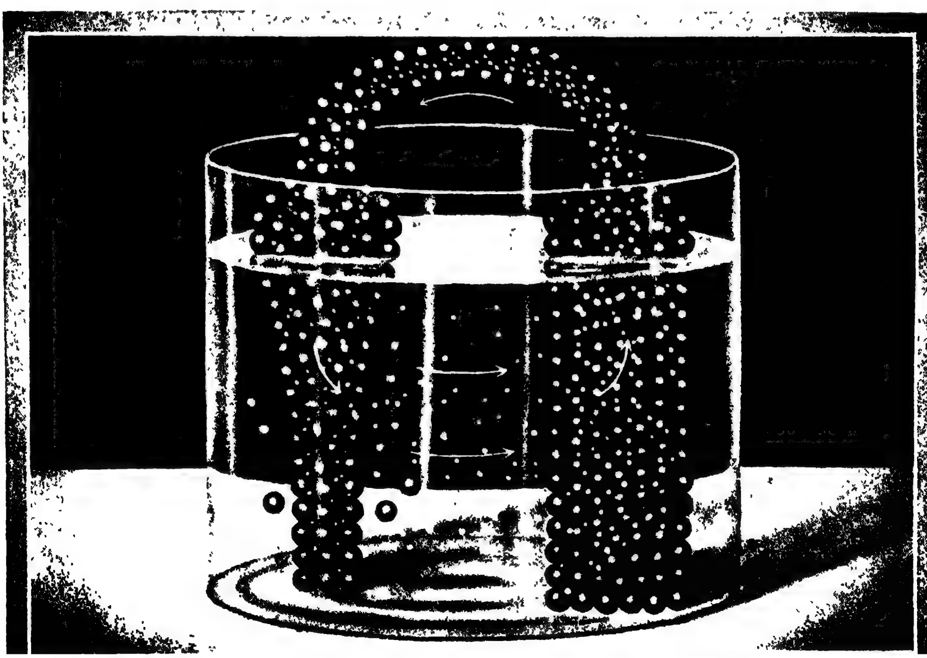
Trying many metals and different fluids, Volta discovered that there was a better method for producing electrical effects than the one in which two substances are rubbed. The best results were obtained when he put zinc and copper into an acid. The combination came to be known as the voltaic (vŏl-tā'ĭk) cell, and it was the first electrochemical device ever known. With this new means of obtaining electricity experiment began in earnest.

There are many forms of this cell, and since Volta's time many modifications of it have been employed. All of these, however, make use of the chemical action which takes place between two rods, called electrodes (ē-lĕk'trōd), inserted in a liquid solution or paste called an electrolyte (ē-lĕk'trō-līt). Volta used rods of zinc and copper immersed in dilute sulphuric (sŭl-fūr'ĭk) acid. The acid acts on the zinc in such a way that electrical charges are stored in the zinc as the latter is eaten away. When a metallic path is provided between the zinc and the copper, outside the cell, an electric current flows between the two electrodes. The copper is gradually covered with bubbles of hydrogen coming from the acid, and these eventually block the current flow. By introducing another chemical into the electrolyte which constantly removes the hydrogen, the current flow is continued until all the zinc is consumed. Then the cell is "dead."

Now, from one point of view, the above explanation is simple. Following Volta's directions, anyone can put together such a cell and make it work. A factory can be



At the left is a simple electric cell consisting of a zinc rod and a carbon rod in a solution of sal ammoniac and water. The chemical action which takes place between the zinc and the solution results in an excess of electrons in the zinc rod and a lack of electrons in the carbon rod. When the zinc is connected with the carbon, the excess electrons flow from the zinc to the carbon. In the picture the arrows point from the carbon to the zinc. This is because we still keep a convention adopted before we learned how the cell really works. In the middle cell, the chemical action is practically the same except that the solution is different and the rods are zinc and copper. In the third cell, we see a cut-away portion of a dry cell. The container is made of zinc, the rod in the center is carbon, and packed between them is a moist paste of sal ammoniac. The chemical action is the same as in the other two cells.



If we could see the tiny molecules in the rods inside an electric cell, we might be in a position to see what it is that moves from zinc to carbon and through the copper wire which connects the two outside the cell. The artist has tried to show the flow of electrons by indicating electrons by the much smaller white dots. You will note that some electrons are also moving through the solution.

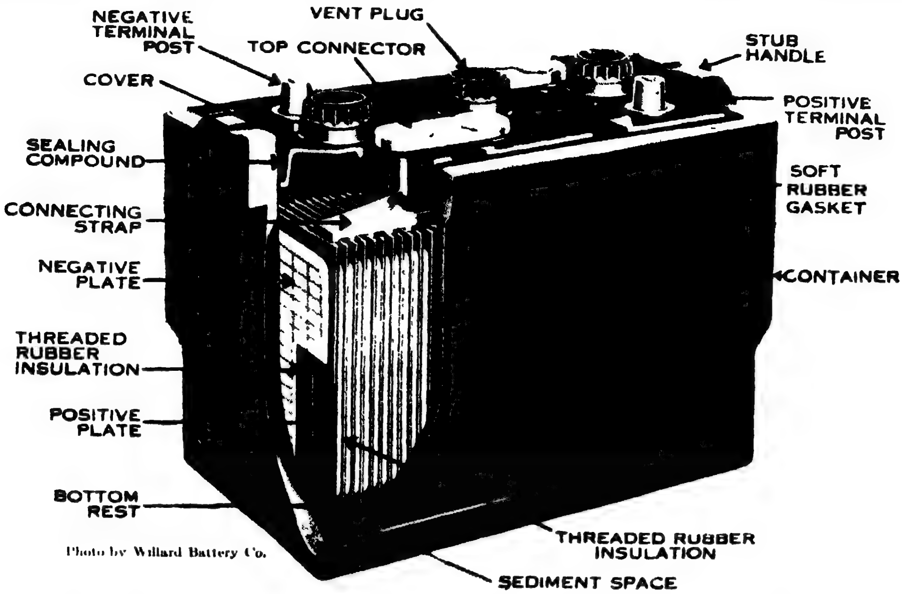


Photo by Willard Battery Co.

This is a storage battery consisting of three cells connected in series. Since each cell develops an electrical pressure of about 2 volts, the battery yields a pressure of about 6 volts. The solution used is sulphuric acid, and the metals - or electrodes- are plates of lead treated with certain chemicals.

built which will turn out thousands of voltaic cells, and all of them will do good work. But not even the manager of the plant can answer the question, "Why does a chemical action cause electricity to flow?" Volta could not answer the question, nor could any of the scientists who followed him. At least, their answers have not been accepted by all scientists. To-day the best explanation seems to lie in a theory about electricity which is called the "electron theory."

How to Make an Electric Cell

Before we begin to explain this theory, let us perform an experiment. Let us make an electric cell which uses materials that are somewhat different from those which Volta used. The chemical action will be the same, but the construction is more like that to be found in the modern dry cell. The experience with actual chemicals in a cell that works will help our thinking and make the explanation easier.

Get from the druggist about half a pound of a salt that goes by the name of ammonium chloride (ă-mō'nĭ-ŭm klō'rīd). It looks like ordinary table salt, but tastes sharply bitter. Dissolve it in a jar of water. Find an ordinary electric bell that is in good condition and can ring when connected with one dry cell. When you are satisfied that the bell is in working order, connect its terminals to a rod of zinc and a rod of carbon. Use wires that are each about two feet long. Then insert the rods in the solution. Probably nothing much will happen; the bell will not ring.

Now remove the carbon rod and heat it thoroughly in a gas flame. When it is very hot, plunge it into a bottle of dilute nitric (nī'trĭk) acid. After giving the rod a chance to soak up the acid, put it back in its former place in the ammonium chloride solution. At once the bell will begin to ring, and will continue to do so for several minutes. To revive the cell, carry out once more the heating and acid treatments. This may be continued indefinitely, until the zinc rod is consumed in the chemical action.

What the Modern Dry Cell Contains

The reason why we used zinc, carbon, and ammonium chloride, instead of the chemicals which Volta used, is that the modern dry

Photo by Alinari

Alessandro Volta was one of the pioneers in the field of electricity. He invented the ancestor of our present-day dry-cell battery. In this picture we see him performing an experiment before Napoleon, who had called Volta to Paris to show French scientists his great electrical invention.

cell contains the materials employed in our experiment. Of course the inside of a dry cell is not a liquid, or else it would not be called dry. However, it does contain zinc, carbon, and ammonium chloride. The chloride, instead of being dissolved, is packed in as a moist paste between the two electrodes.

How the Dry Cell Works

Now how do we explain the dry cell?

First, let us recall that all substances are composed of molecules (mŏl'ĕ-kūl). Molecules are the smallest parts of any substance that can possibly exist, and yet *be* that substance. Thus the carbon rod is made up of molecules of carbon, the zinc of zinc molecules, and the ammonium chloride solution of molecules of this substance interspersed among trillions of water molecules.

Second, all molecules are composed of atoms. In a substance such as zinc or carbon, there is only *one* kind of atom; for zinc and carbon are chemical elements. But in each molecule of the compound ammonium chloride there are six atoms; one nitrogen (nī'trô-jĕn) atom, four hydrogen (hī'drô-jĕn) atoms, and one chlorine (klō'rĭn) atom. Each molecule of water is made up of two atoms of hydrogen and one of oxygen.

Third, atoms themselves are composed of smaller parts. Here we must be careful what we say, for scientists are not sure as to all that atoms contain. As this is being written new discoveries about the inside of an atom are being announced almost every day. There is one thing certain, however, and this is that atoms are made up of bits of electricity. Until very recently these particles were thought to be of two kinds, positive and negative, and they were called "protons" (prō'tŏn) and "electrons" (ĕ-lĕk'trŏn). Now we are told that there is mixed in with these particles also a closely combined electron and proton called a "neutron" (nū'trŏn). And experimenters with cosmic rays and atomic fission tell us of a number of other particles in the atom, but a good deal of work still remains to be done. It will serve our purpose best to consider an atom as containing a complicated nucleus around which a number of electrons revolve as do the planets around the sun. All electrons are alike; only their number and movements change from atom to atom.

For example, a carbon atom contains six planetary electrons; an oxygen atom contains eight.

Since electrons, as well as protons and neutrons, are bits of electricity, we are

faced with the fact that all matter is electricity and that electricity is matter. This is a strange notion; for it means that we ourselves—every muscle, every bone in our bodies, every cell in fact—are, in the last analysis, made of electricity.

With all this in mind, let us turn once more to the dry cell which we made. Think of the molecules of ammonium chloride swimming around among molecules of water. Now imagine that the water molecules split the ammonium chloride molecules, separating each chlorine atom from the other five with which it has been associated in a happy family of atoms. Not only that, but the chlorine atom, in being pushed away, carries with it one extra electron to which it is normally not entitled. This makes for an unhappy state of affairs. The chlorine atom is excited with its extra electron, and one of the hydrogen atoms is upset because it has lost an electron. They try to get back to their previous state, but the water molecules interfere and insist upon this unusual separation.

Now comes the zinc rod in an effort to relieve the situation. It so happens that zinc atoms and chlorine atoms like each other very much. They combine easily to make a new molecule, called "zinc chloride." Each zinc atom ties up two chlorine atoms. When these new combinations are made—and there are millions of them—what happens to the extra electrons borne by the chlorine atoms? They are taken up by the zinc rod which finds itself accumulating a store of extra electrons. Thus, the action results in an excess of electrons on the zinc.

What about the hydrogen atoms that have lost their electrons? They tend to move toward the carbon rod. They cling to the rod, each extracting from the carbon the electron it needs. In this way the hydrogen atoms become full-fledged atoms, containing the normal number of electrons to which they are entitled. But the carbon rod loses in the transaction. The carbon is now lacking in electrons.

Let us now examine the situation that has resulted. The zinc has electrons in excess and the carbon is lacking in electrons. If a copper wire path is provided between the zinc and the carbon outside the cell, is it any wonder that the excess electrons make a dash from a place where they are in excess to a place where they are lacking? Since the copper wire path leads them through an electric bell, they ring the bell as they pass through. The movement of electrons from a place where they are in excess to one where there is a shortage of electrons is called a flow of electric current.

Going back again to the experiment in which we made a dry cell, we find one step that remains to be explained. Why did we heat the carbon rod and plunge it into acid? This is explained when we consider the many hydrogen bubbles which cling to the carbon rod. They must be removed; otherwise the current flow ceases. By heating the rod, we drive some of them away; and the acid removes the rest chemically.

If our readers will take the trouble to break open an old dry cell, they will find the zinc in the form of a cup which holds the contents of the cell. Running down the center is the carbon rod; and packed in between the rod and the cup is a paste of ammonium chloride and a chemical to remove the hydrogen bubbles which tend to cling to the carbon. There are three reasons why a dry cell "goes dead":

(a) The zinc cup is used up.
(b) The paste is dried up.
(c) The hydrogen-removing chemical is used up.

When Volta showed that chemical action may start a flow of electric current, it naturally was asked whether a flow of electricity can produce a chemical change in a solution. To ask was to experiment. Before long, scientists were able to break the molecules of water into their atoms by sending a current through properly prepared water. We call this process "electrolysis" (ē-lĕk-trŏl'ĭ-sĭs). Later, Sir Humphry Davy used a flow of electricity to isolate the element sodium (sō'dĭ-ŭm) from a solution. To-day we are refining copper and other metals by means of an electric current, and are plating metals with other metals in the same way.

Reading Unit No. 3

HOW WE MAKE ELECTRICITY

Note: For basic information not found on this page, consult the general Index, Vol. 15. *For statistical and current facts, consult the Richards Year Book Index.*

Interesting Facts Explained

What is a dynamo? 1–502-6
Parts of the dynamo, 1–502-7
Faraday's principle, 1–504
Obtaining electric current from a coil and a magnet, 1–504
What are the three necessities for producing an electric current without the use of batteries? 1–504-5
How are dynamos rotated at high speeds? 1–506
Volts, amperes, and watts, 1–508-11

Things to Think About

How did Faraday develop his method of producing electric current?
How is current collected from a rapidly rotating dynamo?
How does a transformer step up or step down an electric current?
When is an electric shock dangerous?

Picture Hunt

Trace the flow of electric current from a power house to your home, 1–510
How is electric current measured? 1–509
How might the wind be put to work generating electricity? 1–508

Related Material

Which industries depend upon electricity? 7–379
How is the dynamo used in radio? 10–115-21
How are objects plated with metals? 9–395, 420, 12–92
How is electricity used in forming type for newspapers? 10–57
How are important products obtained from the sea by means of an electric current? 1–557
How are lightning and thunder caused? 1–246
Why is electricity called a form of energy? 1–341, 345, 372

Practical Applications

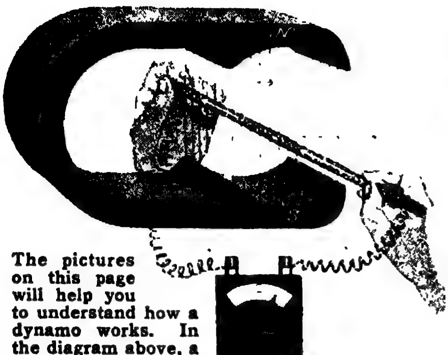
How is electric current for heat and light produced? 1–505-10
How is the voltage of electric current reduced for safety in transmission? 1–510-11

Leisure-time Activities

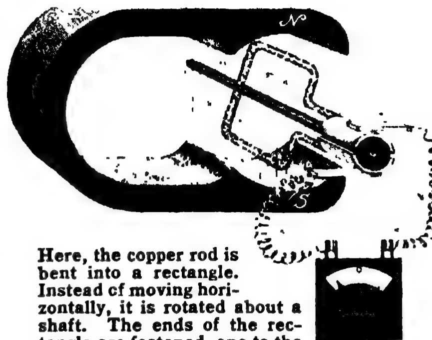
PROJECT NO. 1: Produce induced currents, 1–504.
PROJECT NO. 2: Make models of different early methods of producing electric power, 1–505.

Summary Statement

Electricity is produced in large quantities by the rotation of a coil between the poles of a magnet.

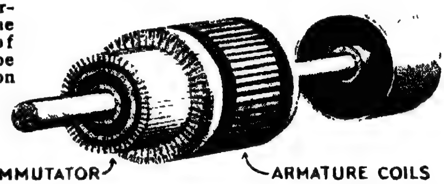


The pictures on this page will help you to understand how a dynamo works. In the diagram above, a copper rod is being moved between the poles of a horseshoe magnet, in the direction indicated by the straight arrows. The vertical lines between the two poles indicate lines of magnetic force. If the N-pole and S-pole are placed as shown and the motion is as described, current of electricity is induced to flow in the copper rod. The direction of this flow is indicated by arrows and the amount of flow may be measured on the instrument attached.



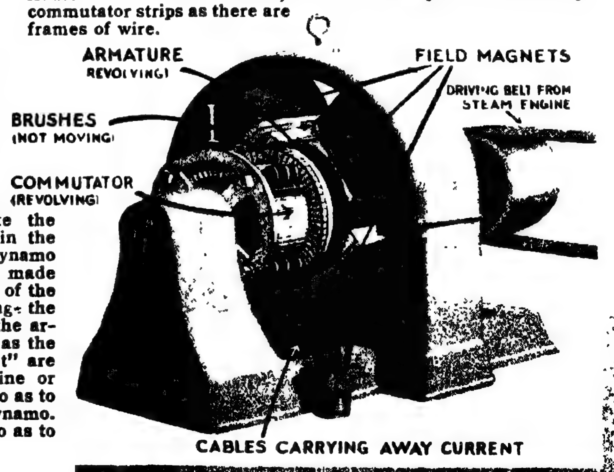
Here, the copper rod is bent into a rectangle. Instead of moving horizontally, it is rotated about a shaft. The ends of the rectangle are fastened, one to the upper and one to the lower semi-cylindrical copper strip. Against these strips rest two straight strips of copper, each connected with a wire leading to the measuring instrument. The motion of the rectangular frame of wire through the lines of magnetic force results in an induced current flowing in the frame of wire. This current flows out of one semi-cylindrical strip, through the meter, and back through the other strip.

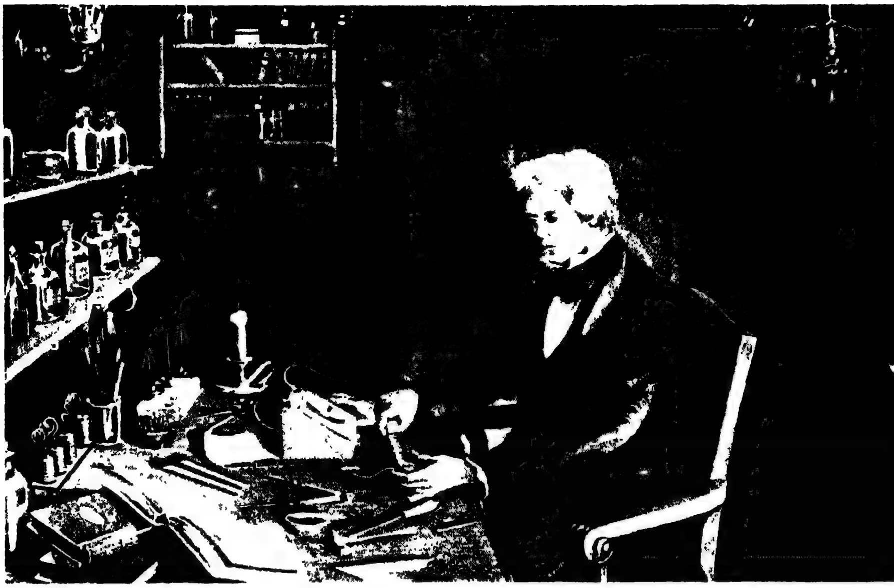
Above is a picture of the magnets in a dynamo. Note that there are four coils, each wound around a large core of iron. Thus, this particular field magnet contains four poles.



The armature, shown just above, is the movable part of a dynamo. It consists of a large number of rectangular frames of wire—such as are described in the corner above. They are set in grooves, and each end of every frame is fastened to one of the copper strips of the cylindrical commutator. Since each frame of wire has two ends, there are always twice as many commutator strips as there are frames of wire.

At the right we see the entire dynamo assembled. The field magnets are in place and the armature can revolve between the poles. Each rectangular frame of wire in the armature has a flow of current induced in it. This current passes to the commutator strips. Since the latter revolve with the armature, they slide past the fixed brushes. The brushes are like the straight copper strips described in the picture at the upper right. In the dynamo shown, however, the brushes are made of blocks of carbon. The purpose of the commutator and brushes is to change the alternating current generated in the armature into direct current, so far as the "cables carrying away the current" are concerned. When a steam engine or other engine drives this machine so as to generate electricity, we call it a dynamo. When we send electricity into it so as to make it turn, we call it a motor.





This is an artist's conception of Faraday performing the most important and most far-reaching of his experiments. He is plunging a bar magnet into a coil of wire. The ends of the coil are connected with an instrument which can measure a very slight flow of electric current. Little did he dream that from the simple act of moving a magnet in the presence of a coil would come the modern electrical age.

HOW WE MAKE ELECTRICITY

Even though Nobody Knows What the Mighty Force Really Is, We Can Generate It and Put It to Work in Thousands of Ways

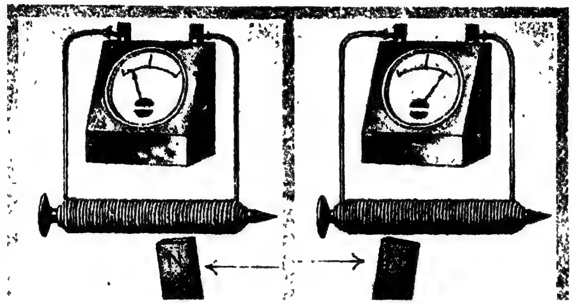
WHEN Galvani and Volta showed the world a better way to make electricity than by the ancient method of rubbing two substances together, they created a new and powerful tool for mankind. Electrical effects ceased to be a matter of mere amusement, and became a force to be reckoned with in the everyday activities of life. Chemical cells and batteries added to man's comforts and, in connection with the telegraph, made business transactions easier and quicker.

But the Age of Electricity would never have come if batteries had remained the only means of procuring electrical energy. After all, a chemical cell yields but a small flow of electrical current. Thousands of cells must be strung together if a great force is desired. Furthermore, the chemicals employed are soon used up, so that the cells "go dead" and must be constantly replaced. To-day we obtain only a small amount of our electrical energy through the use of chemicals. We have learned a new and better way—a way devised by one of the greatest scientists that ever lived—Michael Faraday.

Faraday (făr'ȧ-dā) was born in England in 1791. If you have read the story of his life as it is told on other pages of these books, you will know that his genius attracted the attention of the great English scientist Sir Humphry Davy, who finally took the young man into his laboratory.

In the course of his fifty years of scientific work Faraday performed 16,041 experiments; and it is no exaggeration to say that one of them changed the entire course of human events. With this single experiment we shall now deal.

Both Faraday and Davy were once faced with a difficulty. Requiring a large amount of electric current for a certain experiment, they connected together 2,000 cells, but even these could not furnish the energy they needed. They were struck with the idea that some better means of starting a flow of current should be found.



A coil of wire is wound round an iron nail and connected with the terminals of a sensitive electrical measuring instrument. When the end of a bar magnet is moved near the coil and toward the left, an electric current is started in the coil and the pointer on the instrument moves to one side. When the same end of the magnet is moved toward the right, the current induced in the coil flows in the opposite direction, as is shown by the pointer, which is now moving toward the other side of the scale.

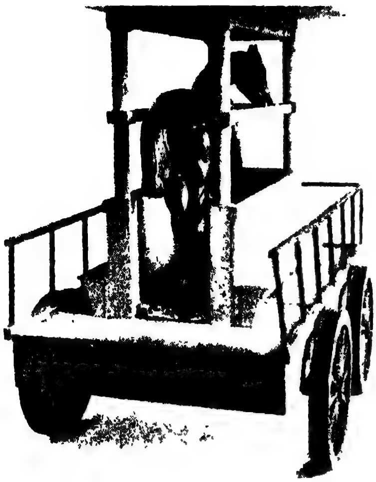
When Faraday learned of Oersted's work with magnets he did not at once see a solution to his problem; but he was greatly interested in the effect. Oersted had shown that a current flowing in a wire could make a neighboring magnet move. "What will happen in the wire," asked Faraday, "if a magnet is moved near the wire?" This question he then put to Nature in many ways. He tried all sorts of things, but did not soon succeed. For nine long years he continued to seek an answer. His greatness is proved as much by the fact that he persisted as by his final success.

Faraday's Great Principle

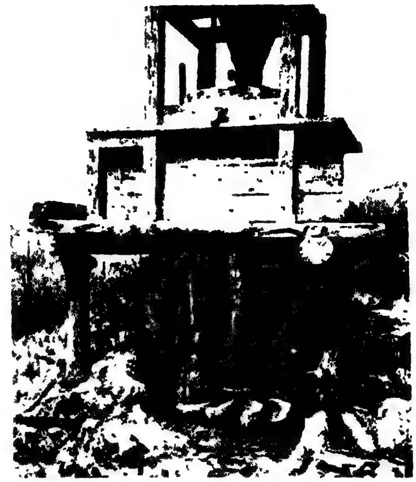
That he did succeed is most fortunate for mankind. There is hardly an electrical device to-day that does not depend upon the answer to the question which Faraday was asking. Electric lights, dynamos, trolley cars, subways, telephones, airplanes, automobiles, motion pictures, radio, and television are but a few of the modern conveniences made possible by the great principle which Faraday discovered. Had it been possible to patent his idea and to continue that patent in force to the present day, Faraday's heirs would now be the richest men in the world. Yet throughout his life Faraday never earned more than $500 a year.

But what was this great principle—this answer that Nature had given to the question which Faraday had raised? If the ends of a coil of wire are connected with some instrument that can register the flow of electric current, nothing happens. The pointer of the instrument remains motionless at the zero mark. That, of course, is as it should be. But when a magnet is moved near the coil or, better still, into the core of the coil, the pointer jerks to one side of the zero mark. Evidently a current of electricity flows through the coil and through the registering instrument while the magnet is being moved.

This was the simple experiment which Faraday performed. Now that he has shown the way, anyone can repeat it. Of course the experiment can be varied in several ways. For example, plunging the magnet into the coil makes the pointer move in one direction; pulling out the magnet causes the pointer to move in the opposite direction. This indicates that the direction of flow is determined by the direction in which the magnet is moved. Again, the results are the same whether the coil is moved and the magnet held still, or whether the magnet is moved and the coil held still. If the magnet is inserted into the coil and both are moved together, nothing happens. One must move with respect to the other; otherwise it is the same as if both magnet and coil were at rest. So three things seem to be necessary in order to induce a current of electricity to flow in a coil: a coil of wire, a magnet, and the motion of one relative to the other.



How to turn a wheel, whether it be a wagon wheel or the armature of a dynamo, has been one of man's chief problems. The horse on the treadmill shown above can move the wagon along; but the device is a crude and poor substitute for electricity.

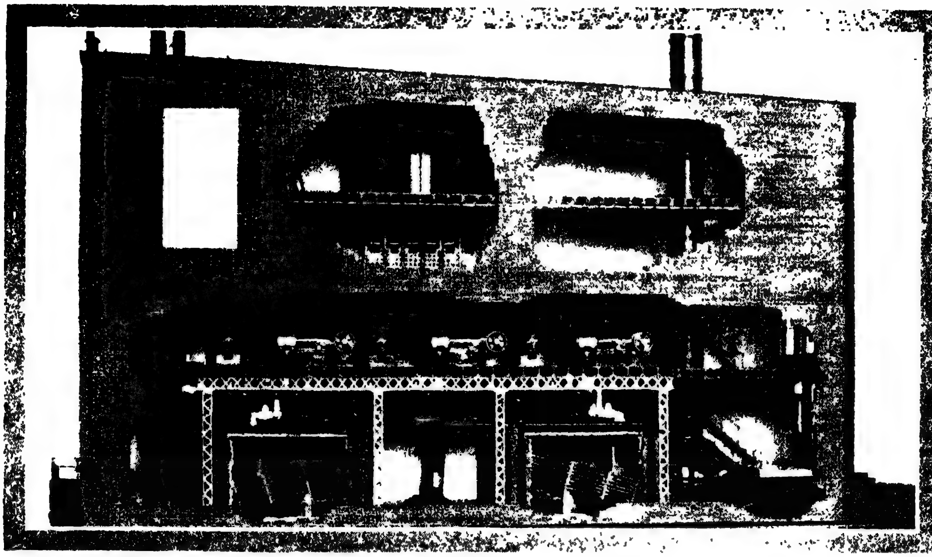


It is thought that the device shown above was invented by the ancient Romans. Flowing water turns the wheel as it falls on the slanting blades that project from the hub. The wheel turns the millstones above it. The millstones grind wheat into flour.

Can you imagine anything more tedious and dreary? This poor man keeps walking for hours, back and forth, back and forth. He gets nowhere, but he does rock the wheel, and so grinds wheat into flour.

This is an old "overshot" wheel. Water flows down the trough, striking the paddles and turning the wheel. Such relics are still to be seen on farms. They are the ancestors of the modern water turbine.

Perhaps our readers are asking, "Where does the electricity come from which flows in the coil when a magnet is moved near it?" The only way to answer this question is to point out that all matter *is* electricity, and that therefore there are trillions of electrons in the copper of which the coil is made. Ordinarily they remain within the atoms of copper to which they belong. Somehow, and we do not know exactly how, the moving



Edison was among the first to make use of the dynamo on a large scale. Above is a model of his first electrical power house, in New York City. To-day it has many gigantic, whirring offspring.

magnet forces some of the electrons to move from one end of the coil of wire to the other. A good way of stating the principle which Faraday discovered is to say that moving a magnet near a coil of wire or a coil of wire near a magnet causes a movement of electrons in the coil.

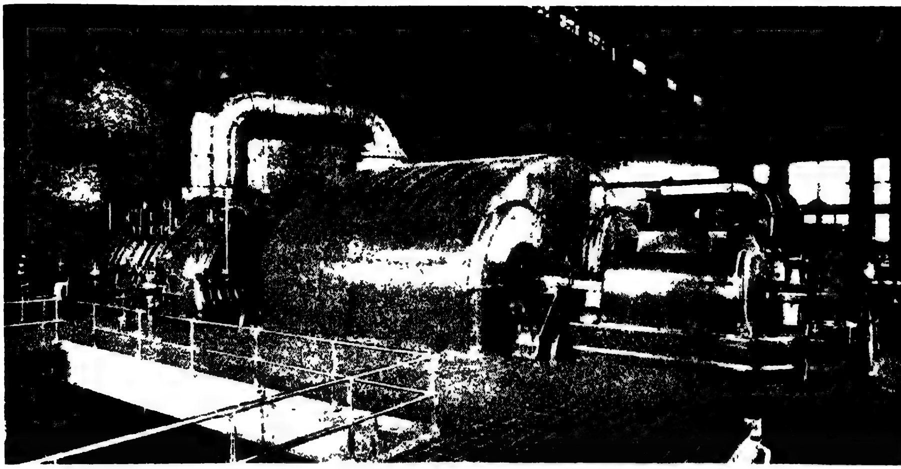
What a Dynamo Is

Since Faraday's principle was such an improvement over the chemical-action method of getting electricity, let us see how easily the amount of current flow may be increased. Each of the three essentials in Faraday's experiment is subject to control. The magnet can be made more powerful, and the greater its strength, the greater the current flow induced in the coil. Second, the coil itself may be made larger, more turns of wire being wound around the core. The larger the coil, the greater the induced current. Finally, the motion may be made quicker. And the faster the motion, the greater the current flow in the coil.

These possibilities were adopted by Faraday and many other experimenters. It was not long before simple ways were found of moving huge coils of wire near powerful magnets. By increasing the speed of the motion, the amount of electrical flow was also increased. In this way a device was built which could transform the mechanical energy of motion into the electrical energy represented by the movement of electrons in a wire. The device was called a dynamo.

As the dusk of night descends upon a modern city, millions of buttons are pushed. The windows of apartment houses and skyscrapers show that electric lamps have everywhere flooded rooms with light. The mere touch of human fingers upon countless little switches has brought a flow of electrical energy from somewhere. If we had eyes that could see through brick, stone, and steel, we should find that a maze of wires runs from each house and building under the city streets to several power stations. In these stations coal is burned in huge furnaces, and the heat boils water into steam. The steam is conveyed in pipes to a number of steam turbines which whiz around at terrific speed. The only purpose of each spinning turbine seems to be to turn the dynamo to which it is coupled. The electrical energy generated by the dynamos flows into the network of wires which spreads throughout the city.

In a dynamo we find two important parts.



From the Hell Gate electric power station this great dynamo, one of the largest in the world, helps supply New York City with electricity. A steam turbine turns the armature, which is capable of generating 165,000 kilowatts of electrical power. Of course the city owns other dynamos besides this one.

One is stationary and the other is movable. The movable part consists of a cylindrical drum around which coils of wire are wound. This is known as the armature (är′mȧ-tûr). The fixed part of the dynamo includes the heavy iron framework which carries also a series of powerful magnets. Of course these magnets are not simple bar or horse shoe magnets. Instead, they are electromagnets consisting of large coils of wire wound round soft iron cores. They are called "field coils."

How a Dynamo Works

When the armature is caused to spin, powerful electric currents are induced to flow in the armature coils. All of these coils are connected together, and the two loose ends are soldered fast to two brass rings fastened to the turning shaft. Two brushes rest against the brass rings as they turn and thus collect the electrical energy. The brushes connect with the network of wires.

In the action of a dynamo, one feature is very interesting and important, though sometimes a little difficult to explain. We have already learned that the direction of current flow in a coil depends upon the direction in which it is moved with respect to the magnet. Now in a spinning armature the coils are moved downward for one-half of each revolution and upward for the other half. Hence the direction of flow induced in the armature will change with each half of a revolution. An alternating current will result.

Of course, a current which alternates its direction of flow is just as useful for most purposes as is one with a flow in one direction only. In some respects alternating current is more economical than direct current Yet dynamos are often built so that they deliver only direct current. In these cases there is another part built into the construction about which we must say a word.

It is called the "commutator" (kŏm′ū-tā′tẽr), and it takes the place of the brass ring. As a matter of fact, it is also a brass ring, except that it is broken up into strips separated from one another by some material that does not carry an electric current. Usually there are twice as many commutator strips as there are separate coils in the armature. As the latter turns, the brushes rest against the strips which slide past.

How the Commutator Works

At any given instant the brushes receive the current generated in one armature coil. The coil is moving past the magnet in a certain direction. Later that direction changes; but by that time it has passed the brushes

and can no longer send its current into the network of wires. Another armature coil is then in contact with the brushes, delivering its current to them in the same direction. This continues as the armature spins; so that only direct current flows into the network of wires.

In the power station to which reference was made in a previous paragraph, steam turbines turn the dynamos. The energy for operating the turbines comes from the burning coal or oil in huge furnaces. The more electrical energy consumed, the more coal or oil is used up. The supply of coal and oil is, as yet, far from exhausted; but considerable time and money is spent in carrying the fuel to the power station. If another means were found for turning the dynamos, a great saving might be accomplished.

It is true that other means are available. There is the wind. If moving air could be harnessed in some way to turn dynamos, a great deal of energy could be saved for the activities of mankind. Windmills have been known for thousands of years, but they are unsuited for turning electric generators. Recently engineers have designed large rotating cylinders which utilize the energy in the wind. Thus far the scheme has not been applied, and we do not know how successful it will be.

The richest source of energy that ordinarily goes to waste is that of moving water. All over the country, streams and rivers have been dammed up to form artificial lakes at high elevation. By allowing the water to flow down through especially-built channels, we can use its pressure to drive water wheels and water turbines. And the water wheels and turbines drive dynamos.

At Niagara Falls several waterpower plants furnish electrical energy for hundreds of miles around.

Here is a ship, the "Baden Baden," which has crossed the Atlantic driven only by the wind. Yet it has no sails. Instead, it carried two vertical cylinders which are rotated by small motors. When the wind strikes the spinning cylinders, a difference in air pressure is set up, and this pushes the whole ship along. The trip took forty days. This rotor ship is the invention of Anton Flettner.

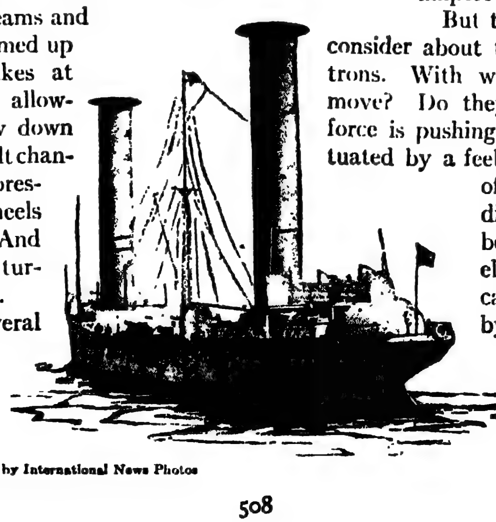
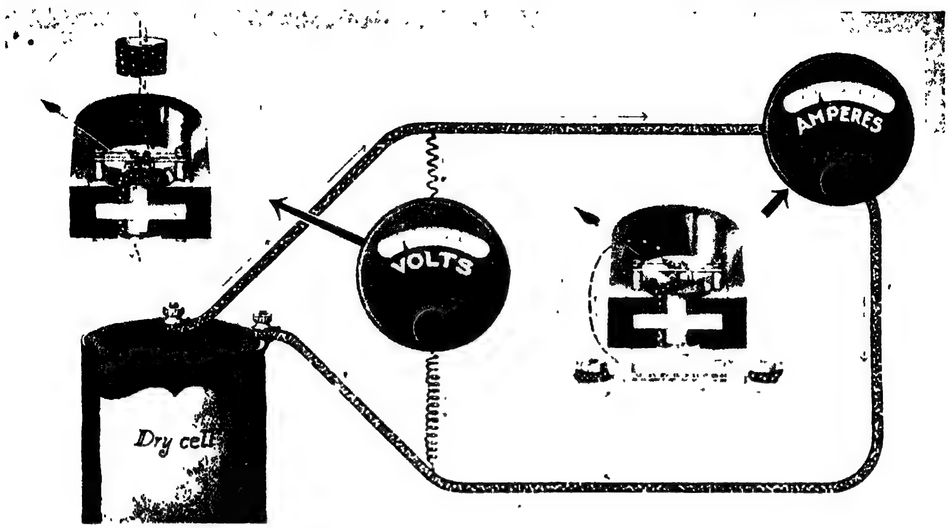


Photo by International News Photos

The plant at Muscle Shoals is another vast project: it was built during World War I, for the purpose of generating electrical power. Another such project in the western part of the United States is the Colorado River enterprise, where Boulder Dam stores great quantities of water for the purpose of turning dynamos.

In order to understand more fully why dynamo current is so much more useful than battery current, we must know some of the things that scientists have learned about the flow of electrons in wires. In the first place, what is the difference between a small amount of electric current and a large amount? Since a current is a movement of electrons, the number of electrons that pass a given point in the wire in a given time is what makes the difference in the size of the current. In other words, the amount of current flow refers to a rate of flow. If two million electrons pass a point in a wire every second, the current flow is twice as great as when only one million electrons pass by. Just as we measure length in inches or yards and weight in pounds, so we measure electric current flow in a unit called an ampere (ăm'pēr), named after the French scientist André Ampère (ôN'drā' ôN'pĕr'), who lived from 1775 to 1836. When six billion billion electrons pass a given point on a wire in one second, we can say that an ampere of electricity is flowing.

But there is another fact to consider about the movement of electrons. With what pressure do they move? Do they move as if a great force is pushing them or are they actuated by a feeble force? This notion of electric pressure is difficult to understand because we cannot see electrons. Perhaps we can grasp the idea better by comparing the flow of electrons in a wire with the flow of water in a pipe. In the latter case, two facts



This diagram will show you how to connect electric measuring instruments. The ammeter, which measures the rate of electrical flow, is always connected "in series" with the circuit. The voltmeter, which measures electric pressure, is always connected across, or "in parallel," with the circuit.

are important. One is the rate of flow in the pipe. The other is the pressure with which the water flows. It is quite possible to have a high rate of flow at low pressure, as in the case of water slowly gushing from a huge pipe. The quantity delivered in a given time is great, but the pressure is low. Or, we might have a low rate of flow at high pressure, as in the case of a thin, sizzling jet issuing from a pinhole in a rubber hose. Here the quantity of water flowing is small, but the high pressure causes the jet to shoot far.

The flow of electrons in a wire may be described in a similar manner. A large electric flow may be at either low or high pressure. A small electric flow may have either high or low electric pressure. The unit in which we measure electric pressure is the volt (vōlt), named after the Italian scientist Volta (1745–1827).

The amount of electric energy delivered by a wire depends both upon the rate of flow and upon the pressure. In fact, we calculate electric power by multiplying the voltage and the amperage. A dry cell delivering twenty amperes at a pressure of one and a half volts represents a power consumption of $20 \times 1\frac{1}{2}$ watts. The "watt" is the unit of electric power, named after James Watt, the inventor of the steam engine. An electric lamp consuming an electric flow of one-half ampere at a voltage of 120 represents a power consumption of $\frac{1}{2} \times 120$ or 60 watts.

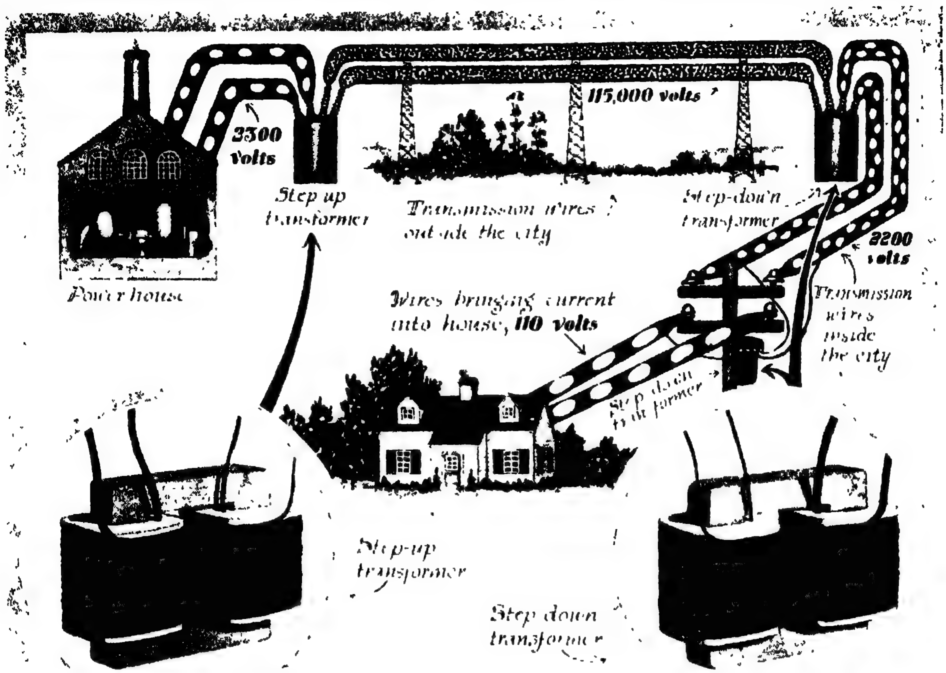
When Electric Shocks Are Dangerous

It is important to note that a dry cell always furnishes a pressure of $1\frac{1}{2}$ volts, while the home current is almost always supplied at a pressure of 110 or 120 volts. A storage cell yields about 2 volts pressure, while the trolley-car line and subway are usually operated on an electric pressure of about 500 volts. A flash of lightning may involve a pressure of 100,000,000 volts.

High voltages are not necessarily fatal to the human body. A great deal depends upon the rate of flow which passes through the body. If the amperage is very low, one feels an electric shock, which usually does little harm and may perhaps do some good. If both amperage and voltage are high, the body is shocked and burned. In such a case death may result.

Why Voltages Must Be Increased

In connecting electrical devices, one must always first find out the voltage at which the device was designed to operate. Should



At the power house, electricity is generated at an electric pressure of 2,300 volts. Since it is more economical to transmit electric energy over great distances at high voltage, the electricity is sent into a step-up transformer. This increases the voltage to about 115,000. The current is carried across country by so-called "high-tension" cables. As the cables approach the city, the high voltage becomes dangerous. Another transformer—this time connected so as to "step down"—converts the 115,000 volts to about 2,200 volts. At this pressure the current flows beneath the pavements of the streets. It would still be dangerous to permit this voltage to enter a house; so another "step-down" transformer is used to change the 2,200 volts into 110 volts, the pressure at which we use the electrical energy from wall sockets, electrical chandeliers, and other fixtures. In the circles are views of the two types of transformer; these views show a difference only in the size of the wire for output and input. The pair of thin wires, in each case, carries in or leads out—as the case may be—the high-voltage current. The heavy wires carry the low-voltage current. When the voltage is high the rate of current flow is low, and vice versa.

it be attached to a voltage line that is too low, it will not operate well, if at all. If the voltage of the line is too high, the device will probably burn out.

The electric current generated by dynamos must push its way through wires that are often hundreds of miles long. The greater the distance, the greater the pressure needed. However, there is a practical limit to the voltage which a dynamo can produce. Engineers have therefore had to find some way to increase voltages after they are obtained from the power station. Furthermore, there is much less energy loss all along the line if electricity is sent at a high voltage. Thus, the electrical engineer is faced with a problem. He must generate current at a fairly low voltage, "step it up" for purposes of transmission, and "step it down" again if it is to be used with safety by the consumer. All this he does with the aid of another device which depends upon Faraday's principle, and which will now be explained.

A Development of Faraday's Experiment

Let us return to the original experiment of Faraday, in which a magnet, moved near a coil, induces a current to flow in the coil. The magnet in question was an ordinary bar magnet. But we may replace this with an electromagnet and get the same results. Now suppose we insert an electromagnet into the core of a coil of wire. Let us call the inside coil the "primary" and the outer

coil the "secondary." Connect the primary coil with a dry cell and the secondary coil with an instrument which can register the flow of current. The pointer registers "zero." If the primary is moved up or down, however, the pointer indicates that current is being induced in the secondary coil.

"Stepping Up" an Electrical Current

Now, instead of moving the primary, disconnect the cell with which it is connected. The pointer moves. Connect it again. The pointer moves again. Continue to make and break the primary circuit. The pointer moves violently back and forth, showing that an interrupted flow in the primary induces a large flow in the secondary.

Finally, arrange a circuit in which the vibrating strip of an electric bell does the interrupting in the primary coil. The effect in the secondary coil is the same as before. If one measures the voltage induced in the secondary and compares it with that supplied to the primary, an interesting fact appears. The two voltages bear the same relationship to each other as do the numbers of turns in the two coils. Thus if the primary coil has 100 turns and the secondary coil 1,000 turns, the voltage induced in the secondary coil is 10 times as great as that supplied to the primary coil. Here, then, is the method we have been seeking for changing low voltages into high and high voltages into low.

Before we apply this method to dynamo current, let us consider another simple fact. In the foregoing paragraph we showed how a constantly interrupted primary current flow may induce current to flow in the secondary coil. Our method of interruption was to use the vibrator of a bell. This is not necessary, for we may use primary current that is already constantly fluctuating in direction and amount. We refer to alternating current. In that event, the effect on the primary coil is to turn it into a fluctuating magnet which is continually changing its polarity and its strength. This results in an induced current flow in the secondary coil.

What Is the Use of a Transformer?

A "transformer" is just such a device as is suggested above. It consists of two independent coils wound round a soft iron core. One coil, of a small number of turns, is the primary; the other, of a large number of turns, is the secondary. A low-voltage fluctuating current sent into the primary induces a high-voltage current in the secondary. A high-voltage fluctuating current sent into the secondary induces a low-voltage current in the primary.

Since an alternating current is already fluctuating to start with, transformers are generally made to operate on alternating current. This gives alternating current a very important advantage over direct current. By means of a transformer we can easily and efficiently change the voltage of alternating current. It is for this reason that alternating current has become popular for home use.

Perhaps our readers have seen transformers used to run toy electric trains. If so, they are familiar with the rather heavy rectangular metal box through which the house current must first flow, before it is safe to use the current on the trains. In this case, a voltage of 120 is transformed into one of about six volts.

Often so much heat is generated in the iron core of the transformer that the entire apparatus has to be immersed in a tank of oil. And the core is made of a series of iron sheets rather than of a single mass of iron.

ELECTRICITY

Reading Unit
No. 4

WHEN THE ELECTRONS START FLOWING

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is an electric spark? 1–513

What is an electric current? 1–513

Good and poor conductors of electricity, 1 514

What is meant by alternating current? 1–516

The speed of electrons, 1–516

What are series and parallel circuits? 1 516-17

The telephone, 1–518-20

Things to Think About

What are the advantages and disadvantages of parallel and series circuits?

How is heat produced by means of electricity?

How are sound waves translated by the telephone?

How may we increase the current output or the voltage of dry cells?

Picture Hunt

How does a switch control the movement of electrons? 1–514

Why does high-resistance wire get hot more easily than wire of lower resistance? 1–515

How is electric heat used to weld automobile bodies into a single unit? 1–513

Related Material

How does a diver communicate with his ship? 10 522

How is the telephone used in certain theaters to aid the deaf? 11–510

What made the long-distance telephone possible? 10–112-13

How are pictures sent by telephone? 10-94-99

How is electricity used to operate electrical heating units? 1–523

What is the economic importance of electricity? 7–499

Practical Applications

How is the electron put to work in the telephone? 1-518-20

How has the use of electricity helped to do away with squeaks and rattles in the automobile? 1-513

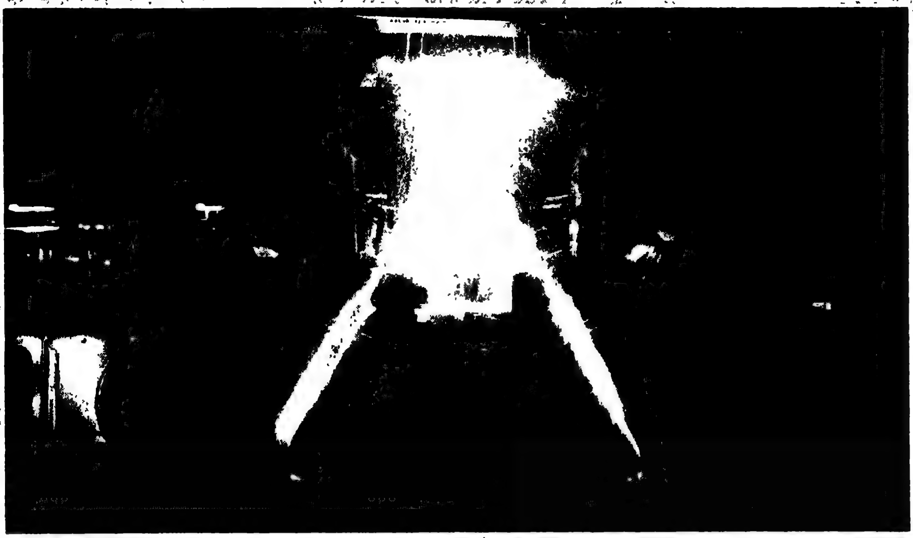
Leisure-time Activities

PROJECT NO. 1: Connect dry cells in series, and in parallel circuit, 1–508.

PROJECT NO. 2: Make a telephone from two radio earphones, 1–520.

Summary Statement

Electrons move more readily if there is a complete conducting path to and from a source of supply.



When electrons jump between two conductors through an air gap, they heat the air molecules and the molecules of vaporized metal which are carried across the gap. This heat is so great that light is given off We call it an electric spark or arc. In the picture we see a tremendous electric arc, so hot that it can melt iron and steel. In fact, the arc is being used to weld together the steel plates of an automobile body. In this way we get rid of squeaks and rattles in a car, and make the automobile body much stronger.

WHEN *the* ELECTRONS START FLOWING

Vast and Mighty Things Begin to Happen from the Forces They Send through the World at Lightning Speed

THE factory covered acres of ground and employed several thousand workers. A constant stream of trains, trucks, and river barges brought tons of raw materials; and another long stream of vehicles carried away the finished products. These consisted of many kinds of household articles, each of special design and each properly wrapped or boxed.

In the main office sat the superintendent. In front of him, above his desk, was a panelboard on which small colored lamps constantly blinked in changing positions. At his right was a long row of buttons, each labeled with the name of a different department head. At his left were a number of telephones and also a microphone and loud speaker.

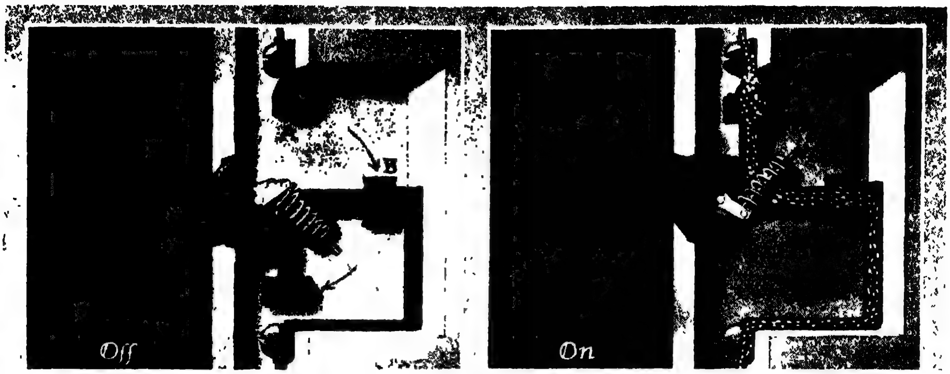
Watching intently the progress of a green light across the panel, the superintendent frowned. Something was holding up an important process. Pressing a button, he leaned toward the microphone. A second later the loud speaker sounded: "John Brown speaking."

"Anything the matter in your department?" asked the superintendent.

"Yes, chief. A blown fuse has stopped a row of machines. We are fixing it in a hurry. Can you send us another mechanic? We need help."

Pushing another button, the chief soon arranged for the necessary help.

A little later a buzzer sounded, to call his attention to the needs of another department. Within an hour he had spoken to ten different men. He had called in his secretary to take dictation, had spoken to his family over a private wire, and had been called on the telephone by a customer in



The diagrams above will show you how a wall switch works. When the switch if "off," a large air gap between A and B breaks the circuit. When the switch is in the "on" position, the space between A and B is bridged by a metallic conductor of electricity; for the piece of metal that was at B has now been moved up to A. The circuit is closed, and an electric current can now flow through the switch.

California. When the air in the room became a little close, he pressed a button which started a ventilating system. As part of a morning's work, he had even held a two-minute conversation with the firm's representative in London.

How We Depend on Moving Electrons

From the narrow confines of his office this man kept in personal touch with every phase of a very complex factory and business. He himself did not move from his seat, but many mechanical and electrical messengers transmitted his words and his commands. One thing and one thing only made possible such complete control—a current of electricity, a flow of electrons.

Not only in manufacturing and in business, but in our homes as well, we are very dependent upon moving electrons. They serve us in so many ways that space does not permit of telling about them all. We can, however, give close attention to the manner in which a flow of electrons behaves.

Most metals are good conductors of electricity. The earth, too, is a good conductor, especially if it is wet. Dry air is a poor conductor, as is distilled water; but impure tap water conducts electrons to some extent. Among the metals, German silver and nichrome—an alloy of nickel and chromium—are among the poorest carriers of electricity.

The poorest metal conductors are better carriers of electric current than are substances like silk, cotton, rubber, glass, and fur. Electrons do not seem to be able to flow through these materials. They are called "insulators" (ĭn'sū-lā'tẽr), and are used to prevent the flow of electric energy from one place to another. Practically every wire used to bring electricity into the home is covered with two or more layers of insulating material.

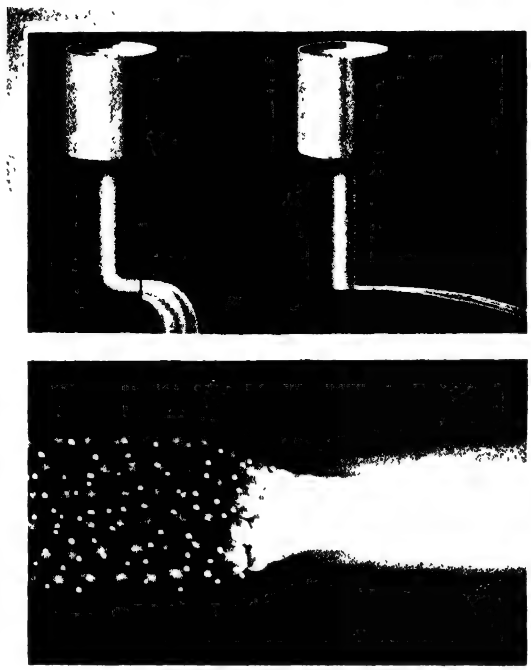
Although air is ordinarily an insulator, it can be made to transmit a flow of electrons under certain conditions. Moisture improves the carrying power of air, as does also an increase of the voltage or pressure forcing the electrons to move. In a lightning flash, many trillions of electrons dash through the air because the voltage is so great. An interesting method for improving the conductivity of air is to decrease its pressure. This method has, in recent years, received a great deal of attention and study. The radio vacuum tube, the X-ray tube, and the neon glow lamp are a few of the inventions that have resulted from this study of the flow of electrons through vacuums and partial vacuums.

The Path of the Electrons

Unless there is a complete conducting path to and from a source of supply, electrons do not begin to move. This is one of the greatest conveniences about the flow of electrons, since it provides an easy means

for starting and stopping their movement. An entire conducting path is completed, except for one small push button or switch in which a gap in the path is furnished. All one needs to do is to close this gap by pushing, and the electric energy flows. Thus electricity becomes the servant of man, always ready to do his bidding and waiting for the final touch which permits the action to proceed.

At the same time this need for a complete path is sometimes a nuisance; for many things can cause an unknown break in the circuit—a loose wire, a piece of dust, or a rusty binding post. When the lights go out because of a "blown" fuse, it is again a break in the path which stops the flow of electrons; but this should be treated as a warning that something is wrong, rather than as a nuisance or a cause for impatience.



The thinner the wire, the greater is the resistance which it offers to the flow of electrons. This is illustrated in the lower picture, in which the artist has tried to show a crowding of electrons and the consequent heating of the thin part of the wire. All this may be compared with the flow of water from a large pipe and a small pipe, as shown in the upper picture. Through the narrow opening, the jet shoots out farther, although the water pressure is the same in both tanks.

And there is another important fact about broken paths. A sufficiently high voltage may jump a gap in a circuit or break through the insulating material. For this reason all buttons, switches, and insulators must always be constructed with due regard to the electric pressure which will urge the electrons to flow in any given circuit.

What Is an Ohm?

We already know that some substances are better conductors than others. One might say that good conductors obstruct the flow of electrons less than do poor ones. Insulators offer so much resistance that practically no electrons can move through them.

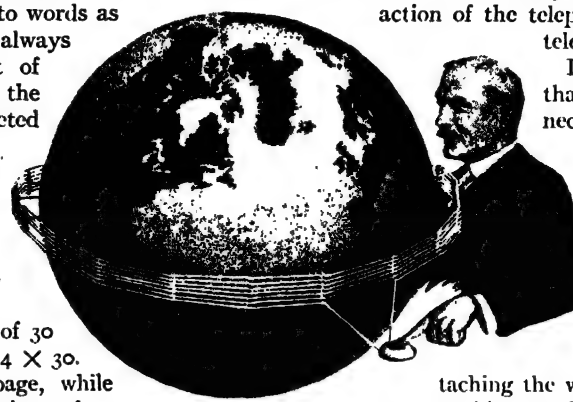
It is often necessary to measure this resistance offered by a conductor. A German scientist named Ohm (ōm) was one of the first men to attempt this, and science has honored his memory by naming the unit of electrical resistance after him. Thus we say that copper wire of a certain size offers a resistance to the flow of electrons of 1 ohm per foot of length; nichrome wire of a certain size offers a resistance of 8 ohms per foot; and so on.

As might be guessed, the thinner and the longer the wire, the greater the resistance. Recently scientists have become very much interested in the resistance of wires that are cooled to a temperature of almost absolute zero, which is 459.6 degrees below zero on the Fahrenheit scale. The resistance becomes so low that the electrons flow through the conductor in great numbers and for a long time. As yet, no practical use for this fact has been found.

We now know three units in terms of which the flow of electrons may be measured. These are the ampere, the volt, and the ohm. The first measures the rate of flow, the second the pressure which urges the electrons to flow, and the third the resistance of the conductor to the flow. While ex-

perimenting with the flow of electrons, Ohm discovered a connection among the three units. He found that the greater the pressure on a conductor of a certain resistance, the greater the flow; and also that, with a certain fixed pressure, the path of less resistance permits a greater current flow. The idea can be put into words as follows: The volts always equal the product of the amperes and the ohms, in a completed electrical circuit. Thus an electric toaster through which 4 amperes are flowing when the voltage is 120 is obstructing the flow to the extent of 30 ohms; since $120 = 4 \times 30$.

On an earlier page, while describing the action of a dynamo, we pointed out that within the armature coil the flow of current was continually changing in direction. This was due to the fact that each coil of the moving armature moved downward during one-half of each turn and upward during the remaining half of the turn. The flow of electrons delivered to the line is therefore an "alternating" one. If the armature revolves sixty times a second, the direction of flow changes twice sixty times every second. Not only is there a change in the direction of the flow; but the amount of flow increases from zero to a maxium value and decreases again to zero during each half turn. A graph of these changes drawn on paper would look like a wave.



When the man in our picture presses the button, an electric current starts to flow in the wire, which is in one continuous coil that travels seven time around the earth. How long does it take for the current to complete the seven trips around the globe? Not counting certain magnetic and other effects which would operate to slow down the flow somewhat, the electric current would do the seven trips in one second.

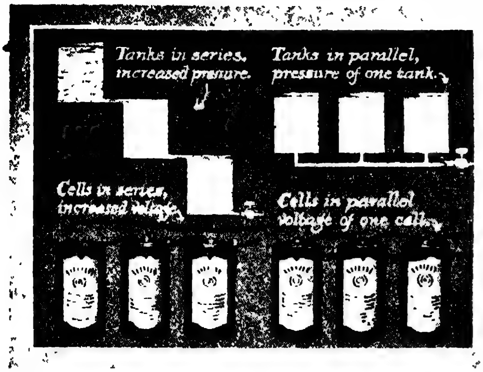
The alternating current supplied to our homes is usually a flow which changes in amount in the way we have described, and which goes through 60 alternations in direction. It is therefore called a "60-cycle A.C."—"A.C." meaning "alternating current." If D.C.—direct current—is desired, the dynamo is equipped with a commutator and brushes. This we have already learned. In the case of direct current, the direction of flow is always the same, as is also the rate. Battery currents always deliver direct current.

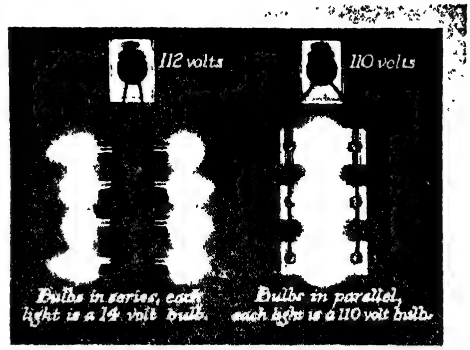
Sometimes when a flow of current is in one direction, the rate still fluctuates in amount. Such a flow is called a "variable current." It is extremely important in the action of the telephone, radio, and television.

Let us suppose that we wish to connect a small lamp so that it will be lighted by a cell when we press a button. The cell stands to the left of the lamp as we face north. Instead of attaching the wires directly, we could carry them westward for thousands of miles until the entire globe had been traversed. Finally we should arrive at the starting point where the wires are connected with the lamp. If this were done at the Equator, there would be nearly 25,000 miles of double wire between the cell and the lamp. As the button is pressed, the electrons must flow through the entire distance before the lamp can light. How long after you close the circuit does the light appear? It would light in a fraction of a second; for electrons flow through a conductor at the rate of almost 186,000 miles a second. Such speed is almost unimaginable. It is fast enough to travel seven times around the earth at the Equator in a second. Of course, one dry cell is hardly able to push electrons through such a long conductor.

A Connection in Series

Several different conductors may be connected in such a way that electrons will flow first through one, then through the next, and so on. The lamps on a string of Christmas tree decorations are a good example of this way of connecting conductors.





The cut at the left illustrates the effect of connecting dry cells "in series" and "in parallel." Just as in the case of water tanks connected in series, the pressure—or voltage of electricity—is increased. Connection in parallel, both of water tanks and of dry cells, results in no increase of pressure; but it provides a flow for a longer time. At the right is an illustration of the effect of connecting lamps "in series" and "in parallel." Eight lamps, each built to light normally at an electrical pressure of 14 volts, may be connected "in series"—without danger of burning them out—to a source of current where the pressure is 112 volts. The connection here is such that if one lamp burns out or is unscrewed, all the other lamps go out. At the extreme right of the page three lamps, each built to light normally at an electrical pressure of 110 volts, are shown connected "in parallel" across the 110-volt line. Each lamp is independent of the others.

When one lamp burns out, a gap in the circuit results which causes all the lamps to go out. When the defective bulb is replaced, the entire string lights up once more, since the electrons can now flow through one lamp after another in a completed circuit. Such a connnection is called a "connection in series." It adds the resistance of each conducting path to that of all the others in the series and makes necessary a large electric pressure to force electrons through them all.

What Is the Connective Parallel?

Cells, too, are connected in series when the carbon of one cell is attached to the zinc of the next cell. In this way, the pressure of each cell is added to that of the others. Thus the voltage of four cells connected in series is $4 \times 1\frac{1}{2}$, or six volts.

Several conductors may be connected so that electrons will flow through all of them at the same time. The electric lamps which light up our homes are not like those on a Christmas tree. One lamp can burn out without affecting any of the others, because the flow of electrons takes place through all of them at the same time. An examination of the connecting wires shows that each house lamp is attached to the source of current by an independent pair of connecting wires. Such a scheme is called a "connective parallel." Here the resistance of each path is not added to the others. In fact, the total resistance is decreased by virtue of the fact that so many avenues of flow are provided.

When cells are connected in parallel, all the carbons are attached to the same wire and all the zincs are connected with a second wire. The two wires act as the source of current supply. The voltage, in this case, is not increased, no matter how many cells are used. The voltage remains at $1\frac{1}{2}$, which is the pressure exerted by any one cell. The advantage of a parallel connection of cells lies in the fact that they can, in this way, deliver a larger rate of flow for a longer time.

A good example of parallel connection is to be found in the signaling buttons on a bus, trolley car, or house elevator. Every button rings the same bell.

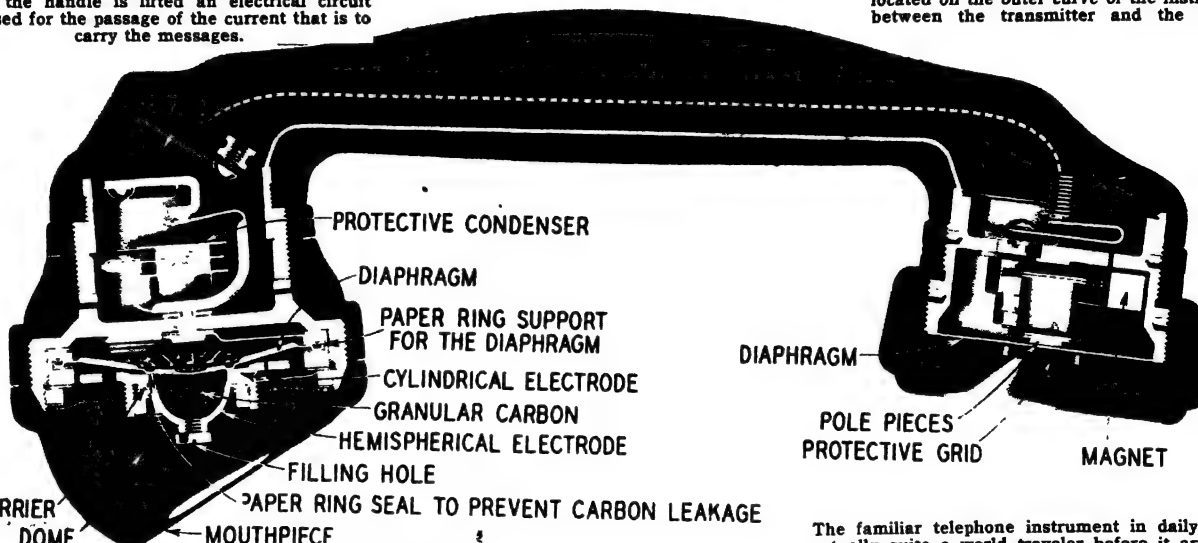
Bell's Work on the Telephone

The experiments which led Alexander Graham Bell to the invention of the telephone all had to do with the flow of electrons in a completed conducting path. Bell did not begin with the idea of sending speech through wires. He wanted merely to devise a better form of telegraph. He was quite familiar with the work of Morse and understood how the latter made use of an electric

The so-called "French telephone," or hand set, shown in the diagram below, is coming more and more to replace the older "desk set," in which the receiver was hung on a hook. In a hand set the receiver and transmitter are at opposite ends of a handle shaped in such a way as to bring the mouthpiece to the proper distance from the lips when the receiver is held against the ear. The handle rests on a cradle, or stand, so devised that when the handle is lifted an electrical circuit is closed for the passage of the current that is to carry the messages.

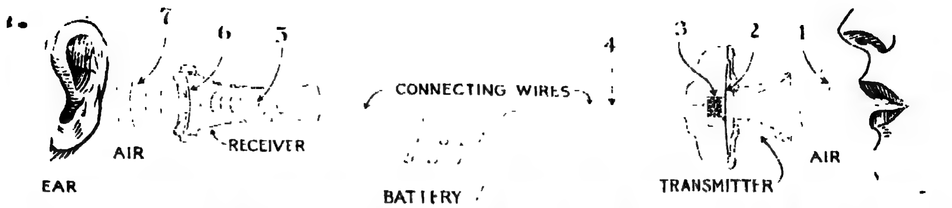
The end shown at the left below contains the transmitter, which is pictured in cross section. Sound waves entering the mouthpiece strike the diaphragm, whose thin edge you see, and cause it to vibrate in accordance with the sounds that reach it. Fastened against the diaphragm is a capsule containing granules of hard carbon.

The electrical current passing continuously through those hard carbon grains—when the instrument is not resting on the cradle—is strengthened by the varying compression of the grains resulting from the vibrations of the diaphragm. In this way the sound vibrations are converted into fluctuating electric currents in the telephone circuit. Wires enter and leave the telephone through the channel located on the outer curve of the instrument, between the transmitter and the handle.



The receiver is shown in cross section at the right. About the ends of the horseshoe magnet is a coil of wire. The incoming fluctuating currents passing through this coil increase or decrease the pulling power of the magnet. As the pulling power of the magnet is increased or decreased, the diaphragm is made to vibrate and to produce sound waves from the open end of the receiver.

The familiar telephone instrument in daily use is actually quite a world traveler before it arrives at your home. The materials that go to make up its various parts are assembled from every corner of the globe. These materials include rubber, silk, cotton, flax, wool, coal, iron, lead, copper, zinc, nickel, aluminum, gold, silver, platinum, mica, antimony, hemp, tin, and asphalt.



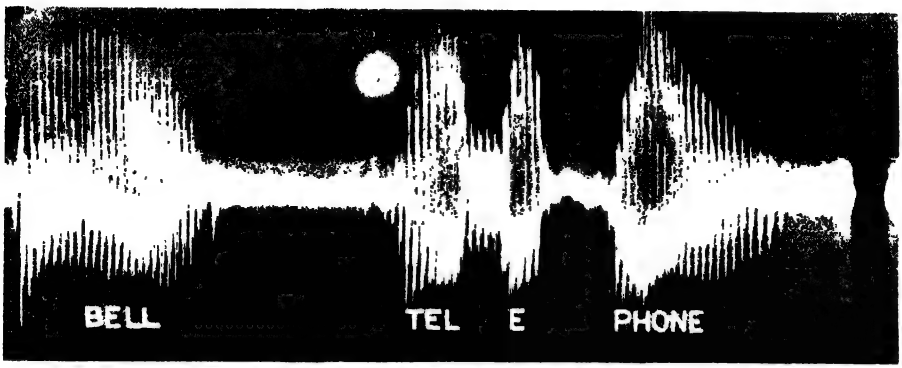


Photo by Bell Telephone Laboratories

Directly above is a picture of the air vibrations as they come from your lips when you say "Bell telephone." When these vibrations pass through the transmitter, they are turned into electrical impulses, but their arrangement is the same. At the top are the various parts of the telephone. No. 1 shows you the sound waves entering the transmitter. No. 2 is the diaphragm; No. 3, carbon granules; No. 4, connecting wires; No. 5, coil with iron core; No. 6, diaphragm; No. 7, sound waves leaving receiver.

flow through a coil to click a piece of iron. But as a student of speech and music, he wished to utilize the same flow for more pleasing sounds than a sharp click. He thought that musical tones could also be conveyed by moving electrons. Of course Bell did not think in terms of electrons, since he knew nothing of the electron theory.

The Essential Parts of a Telephone

Elsewhere in these volumes we have told the fascinating story of how Bell and his assistant struggled for years with the problem of improving the telegraph. The thrill which came when they stumbled on a result that pushed the telegraph forever out of their minds was one seldom experienced by human beings. They were thrilled by the fact that a flow of current can transmit faithfully the tiny fluctuations of speech. They proceeded at once to build the instrument which, in only a few decades, became the modern telephone.

As we examine the instrument which stands on our table at home, we see a transmitter, or mouthpiece, and a receiver through which we listen. In our mind's eye we see a similar combination in the home of the person to whom we wish to speak. Between the two homes stretch wires that first reach a telephone exchange where proper connections are made. Stripped of all complications such as dialing devices and signaling bells, the modern telephone consists of three essential parts: a transmitter, a circuit, and a receiver.

How a Telephone Works

The transmitter is a hard rubber horn held fast in a round base. Just back of the horn is a disk. Talking against this disk causes it to vibrate in accordance with the sounds made. The movements of the disk push back and forth upon a number of sharp carbon chips in a metal container. Wires lead to the transmitter, carrying a

small direct current flow through the carbon chips. When the disk is motionless—that is, when no one is talking into the mouthpiece—this flow of electrons is at a constant rate. The flow is small because the loosely packed chips offer great resistance; but when the disk begins to vibrate, the carbon chips are pressed closer together and released. This results in a variable rate of current flow. In fact, the variations in the flow correspond to the vibrations of the disk. If one says "Hello" into the mouthpiece, the disk vibrates in a "Hello" manner and the resulting variable current is a "Hello" current. Thus, the sole purpose of the transmitter is to change the fluctuations of speech into fluctuating electric currents.

The circuit includes a source of direct current at the central exchange, a group of conducting wires, a signaling device, and several means for "stepping up" the voltage of the speech current in order to carry it over long distances. The hook on which the receiver hangs moves up when the receiver is lifted. While the hook is down, the bell circuit may operate, but the speaking circuit cannot. Upon the lifting of the receiver, the signaling path is broken and the speaking circuit is ready to operate.

Two devices are to-day employed for increasing the voltage needed for long distances. One is the induction coil about which we have learned in a former story, and the other is the vacuum tube, which will be explained in a later one.

What Is the Receiver?

In many of the modern telephone instruments the receiver and transmitter are built in one piece, so shaped that one hand can hold the proper parts to the mouth and ear. In the older form of instrument, the receiver is an independent device. In either case, however, the receiver consists of an electromagnet wound around a permanent steel magnet. Near the permanent steel magnet is a round iron disk. All parts are incased in a hard rubber frame, shaped to fit the human ear. The ends of the electromagnet coil are drawn out of the case and connect with the circuit previously described.

Let us now consider what happens when a "Hello" current reaches the telephone receiver. Prior to its arrival, the iron disk is held motionless by the steel magnet, though the disk is free to vibrate. The arriving current is a variable one. Hence it will result in a fluctuating magnetic pull on the part of the electromagnet. The latter therefore weakens and strengthens the effect of the permanent magnet. The disk then responds by being pulled over more and by being released, following the current fluctuations. In other words, the disk vibrates back and forth. Exactly how does it vibrate? In accordance with the variable current that arrives. But these variations are due to the word "Hello." Hence the disk vibrates in a "Hello" manner, producing the sound of the word "Hello."

The Two Receivers Bell Used

When Bell and Watson built their first telephone, they did not use the carbon chip transmitter. That was an improvement for which Edison was responsible, some years after the invention was announced. Instead, they used two receivers, one for talking and one for listening. That this is possible can be proved by anyone who cares to connect two radio head-sets. The headsets are telephone receivers compactly built. No source of current is necessary—just two wires, each 100 feet long, between one headset and the other. Using one of the receivers as a mouthpiece and the other as an earpiece, we can easily carry on a conversation, provided that the intervening distance is not too great. What is the explanation?

Talking into a receiver causes the iron disk to vibrate. Since the latter is a magnet by induction and since it is moving near a coil of wire, a current is induced to flow in the coil. This is in accordance with Faraday's great discovery. The induced current flow fluctuates in accordance with the sounds made. Hence a speech current is generated. Again, sound vibrations have been changed into a fluctuating flow of electrons. The receiver at the other end changes the variable current back into sound in the manner already described.

ELECTRICITY

Reading Unit No. 5

HOW THE ELECTRONS WHIRL OUR WHEELS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What are the different effects of the flow of an electric current? 1–522-23

What determines the amount of heat developed from an electric current? 1–523

The electric iron, 1–523

The kilowatt-hour, 1–523-24

Dangers of electricity, 1–524

Fuses, 1–524

The electric lamp, 1–525

The electric motor, 1–527-28

Things to Think About

What is believed to be the cause of the Aurora Borealis?

How may electricity make a wire red-hot?

Why do electric lamps "burn out"?

What makes an electric motor revolve?

Picture Hunt

How is electricity used in the modern kitchen? 9–442

What are the necessary parts of a modern electric lamp? 1–525

What happens in a flashlight when the current is turned on? 1–527

Related Material

What were Edison's inventions? 13–442-43

How is electricity used in motion pictures? 10–503-6

How is traffic controlled by means of electricity? 10–156

How is electric current manufactured? 1–506-8

How is electricity used in refrigeration? 1–410, 10–518-19

How is electricity used in lighthouses? 10–226, 228

How is electricity used in mines? 9–417, 445

Practical Applications

How does modern civilization use the electric motor? 1–528

How does the housewife use electricity to make her work easier? 1–522

Leisure-time Activities

PROJECT NO. 1: Examine your flashlight and learn how it works, 1–527.

PROJECT NO. 2: Produce heat from electricity, using dry cells, 1–522-23.

Summary Statement

Electricity furnishes man with light, heat, and power. More and more, it is becoming the most convenient means of doing the work of the world.

Photo by General Electric Co.

Electrons run our stoves, refrigerators, lights, radios, clocks, toasters, washing machines, dishwashers, irons, coffee-grinders and makers, juicers, and mixers. How many electrical devices can you find in this kitchen?

HOW *the* ELECTRONS WHIRL OUR WHEELS

This Will Tell about the Vast Machines That Send Us Light, Heat, and Power through the Wires

IF A list were made of all the different uses to which a flow of electrons may be put, the items in the long list could be divided into four different kinds. First there would be those uses that have to do with chemical action. On a former page we have told how an electric current produces chemical changes and how these may result in a flow of electrons. Second, there would be a group of uses which depend upon magnetic effects. Oersted showed that the flow of current can make a magnet move, and Faraday proved that a moving magnet can make electricity flow. The third kind of use for an electric current has its effect upon our nerves and the body in general. We feel a "shock." Under some conditions this effect is beneficial; under certain other conditions, it may be injurious and even fatal. About the fourth type of use for the flow of electrons we have said little thus far. Whenever a current flows through a wire, the wire gets warmer. This effect has many interesting uses. All the facts relating to the behavior of electrons make up the science of electronics (ē-lĕk-trŏn'ĭks).

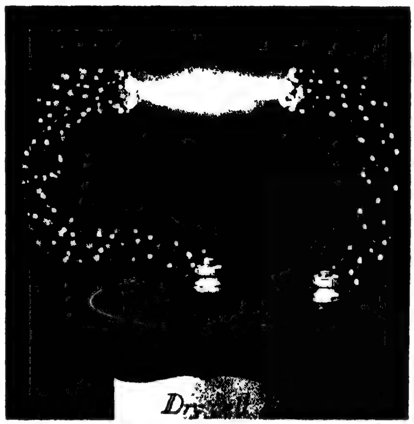
If you allow the ends of a piece of wire to touch the terminals of a new dry cell, you are likely to smell smoke before long. Then you may see the cotton covering around the wire getting charred. You will probably disconnect the wire pretty quickly.

Afraid that your dry cell is ruined, you decide that you may as well use it for other heating experiments. You try an iron wire, a copper wire, and several other kinds. In each case the conductor gets hot, but to a different degree. You then begin to wonder whether a wire can be made hot enough to glow; but one cell does not seem to be

enough for this. You grow so interested that you make up your mind to sacrifice other cells if necessary. Eventually, you try four cells connected in series, and they make a thin iron wire get red hot. Later you connect a short copper wire across the terminals of an automobile storage battery. In a flash, the wire melts from the heat. The sport is rather dangerous, both to yourself and to the battery; but one could learn a good deal from the experiments.

In the first place, you find that the amount of heat generated depends upon the amount of current flowing—the greater the current, the greater the heat.

Secondly, the kind of wire used is important. The good conductors develop less heat than the poor ones, if all other conditions are the same—in other words, the greater the resistance, the greater the heat.



When electrons flow in great numbers through a piece of wire that resists the flow, the wire grows hot. In time it may get hot enough to glow and even to melt. This explains the glow of the short wire in the electrical circuit above.

Thirdly, it always takes a little time for wires to get hot. The longer the current flows, the greater is the heat generated.

Finally, you discover that of the three factors, current strength, resistance, and time, the first is the most important. A slight increase in the amount of current more than makes up for a slight decrease in resistance or in time duration.

Scientists who have studied this matter carefully combine all of these facts in one statement. To calculate the amount of heat developed, they multiply the square of the current flow by the resistance and by the time of flow. Thus, a flow of 2 amperes through a conductor of 5 ohms resistance during a time interval of 20 seconds, develops 400 units of heat. The total is obtained as follows:

$$2 \times 2 \times 5 \times 20 = 400$$

A common device for using the heat in a conductor of a flow of electrons is the electric iron; embedded in the interior and surrounded by asbestos is a coil of high-resistance wire, called the "heating unit." The metal used is frequently an alloy of nickel and chromium. This alloy has not only a high resistance but a high melting point as well. Furthermore, it is not easily affected by the oxygen of the air. In an electric iron, the length of the heating wire is usually made such that 120 volts pressure can force through it a current flow of about 5 amperes. Reading the label plate of such an iron, we find the following legend: "120 volts—600 watts." Obviously, the watts are calculated by multiplying the voltage by the amperage, since $120 \times 5 = 600$.

Many other electric heating devices are employed to-day in the home and in industry. All of them contain a "heating unit" of the kind described above. The length of wire used, however, is not the same in all. An electric toaster permits about 3 amperes to flow, a coffee percolator 5 amperes, a cooking stove 7 to 10 amperes, a warming pad about 2 amperes, and a hot-water heater from 12 to 15 amperes.

Why Electricity May Be a Menace

It is very convenient to use electricity for heating purposes. The heat is always ready at hand and it involves no dirty fires, smoke, or ash removal. But it is also rather expensive. Some notion of the cost may be got by considering the charges which electric companies make. Their meters read in units called "kilowatt-hours," and for each kilowatt-hour the charge is about seven cents. Of course, it may vary in different places. Now a kilowatt is 1,000 watts.

Using electric energy for one hour at the rate of 1,000 watts adds seven cents to the bill. Thus, a 600-watt electric iron in use for five hours consumes 3,000 watt-hours of electric energy. This is the same as 3 kilo-watt-hours, and it costs about 21 cents. In the course of a month the bill will run up.

Like many other strong servants of man, electricity is a menace and a danger when it gets out of control. The modern home is enmeshed in a network of wires through which currents flow. In the walls, ceiling, and floor of every room wires are being heated whenever electricity is used. What shall keep them from getting hot enough to set fire to the house?

The first measure of safety is taken by the electrician when he installs the wiring system. He is required by law to do his work in certain ways. Wires must be of the proper thickness and kind; they must be insulated and incased in a fireproof conduit. The number of sockets and outlets is carefully specified, as is the number of switches. If the government inspector finds anything that is not in accordance with the "Electrical Code of Rules and Regulations," he insists that the work be done over again. He may even take away the electrician's license if they have been disobeyed in any way. Above all, the inspector examines the fuse boxes and the fuses, for these are the greatest protection we have against fires from overheated electric wires.

Photo by General Electric Co.

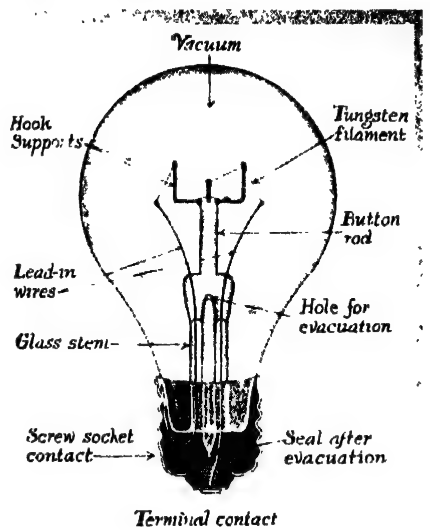
Above are portraits of two of the greatest electrical wizards the world has ever produced. They are Edison, at the left, and Steinmetz. Both are now dead, but the products of their genius continue to add comfort and convenience to our lives to-day.

What is a fuse? The best way of finding out is to break open a fuse cartridge or, if it is a screw receptacle type of fuse, to look into the small mica window. In the latter case, one sees a bit of wire which bridges the gap between the bottom of the receptacle and the side. Removing this wire, one finds it soft and pliable. And it melts very easily. The heat of a match is sufficient to liquefy the metal. In a cartridge fuse the same kind of wire will be found.

Since the piece of fuse wire is part of the electrical circuit, all the current used in a given part of the house must pass through it. Hence it gets warm. Whether or not it melts depends upon how thin it is; for less metal requires less heat to melt it. Should the fuse wire melt, the conducting path is broken and no current at all can flow in that section of the circuit. Thus the fuse controls the maximum amount of current which can flow. A five-ampere fuse melts when more than five amperes are caused to flow; a ten-ampere fuse melts when the current consumption goes beyond ten amperes. Fuses are stamped with a number indicating the maximum amount of current which they will allow to pass without melting. Our homes are usually fused for a maximum current flow of 10 amperes. Before putting in a fuse, one should determine its carrying power. A large fuse may seem convenient, since it is less likely to melt and interrupt the use of current. But a fuse that is too large offers no protection. It may permit so great a flow that the wires in the walls will

get hot enough to start a dangerous fire. A fuse that has melted is a "blown" fuse. It must be replaced, if we want to use the current again. The most common reason for "blown" fuses is the "short circuit." What causes a short circuit?

We have learned that the smaller the resistance which a conducting path offers, the greater is the flow of electrons. If, while the current is flowing in a completed circuit, another path is suddenly provided whose resistance is only one-tenth of that in the old path, ten times as much current will flow through the new path. This new path is called a short circuit. Defective wiring will frequently bring the two wires leading to a lamp to touch directly instead of being connected through the lamp filament. The resistance of a direct touch of this kind may be 100 times less than that of the path offered by the lamp. The sudden rush of 100 times as much current through the "short circuit" melts the fuse.



Here are all the essential parts of a modern electric lamp. Notice how thin is the wire which the electricity makes hot enough to glow. Notice, too, how this filament of wire is supported. Of course there must be no oxygen inside the globe, for then the wire would burn up.

The modern electric lamp consists, essentially, of a metal wire incased in a closed glass globe. The wire is made of tungsten, and the space around it either is a vacuum or is filled with a gas that contains no oxygen.

Since the heating effect produced by the flow of an electric current has been known for more than 125 years, one wonders why the world waited until 1879 before Edison invented the electric light. As a matter of fact, many men before Edison thought of heating a wire hot enough to make it glow by means of electricity. But for two reasons they failed to make a workable lamp. They did not have at hand any large source of current, such as the dynamo. They were compelled to use battery current. And no one before Edison devised a scheme for removing the air from the glass globe. As long as the oxygen of the air surrounded the white-hot wire or filament, the wire was simply burned up very quickly.

The story of Edison's struggles in perfecting his lamp is one of the most romantic in the history of science. Some of the details of this story have been described elsewhere in these volumes. But there is one aspect of Edison's work with the lamp which must be mentioned here, for it resulted in a development which made the radio possible.

The hot filament does not burn, because there is no oxygen to support combustion in the globe. Why, then, does not the filament last forever? Everyone knows that lamps do "burn out" eventually. The words "burn out" are really an error. If we look at a used lamp, we find that the inside of the glass globe is blackened, but that most of the filament is still intact, except for a single tiny break.

Why a Lamp Burns Out

In order to understand what has happened, let us remember that the molecules of a heated body are vibrating violently. There are trillions of molecular collisions, in which some of the molecules are thrown out of the filament. These are deposited on the inside surface of the glass, causing it to become discolored. It is as if the hot metal wire were boiling away from the solid state directly into the gaseous. Since there is no air pressure within the globe, this boiling process is unrestrained. In the end, some portion of the filament loses so many molecules that it is weakened. A slight jar causes

Photo by American Museum of Natural History

It is only in northern lands that this beautiful display, known as the "northern lights" or aurora borealis (ô-rō'rȧ bō'rē-ă'lĭs), is seen at its best. The Eskimo sees it in all its mysterious splendor, when great rays of colored light play over the snow in pearly waves. But the sight is visible as far south as New York, where, in pale yellow light, it ripples over the northern sky or gleams like a pale white band with flickering, flamelike edges. Occasionally it is like a curtain that waves slowly back and forth. The aurora is one of the tricks that electricity can play. It takes place high in the upper air, some fifty miles up or more and sometimes as high as two hundred miles. It is usually finest at periods when the sun has a great many spots. No one knows exactly what makes it, but it is noticeable that at the time of a brilliant aurora there are magnetic disturbances everywhere. They used to upset the work of telegraph operators, who, before their instruments were perfected, sent messages that got nowhere at all. People living south of the Equator see an aurora that plays over the South Pole; and there, as with us, it comes oftener in summer.

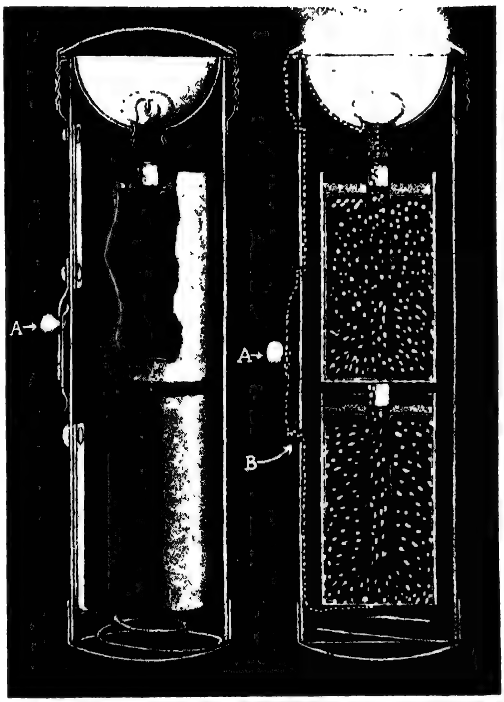
it to snap, and so the conducting path is broken. The lamp is then said to be "burnt out."

Edison was much interested in this boiling away of the filament in a vacuum. He called attention to it, but did not find time to study it further. Other men later investigated it and performed experiments which led to the invention of the vacuum tube—the heart of radio receiving and transmitting sets.

The evaporation of a heated filament in a vacuum led also to several improvements in

electric lighting. One engineer thought of the idea of taking out only the oxygen from within the lamp. He left the nitrogen and other gases behind. He was glad to find that this not only lengthened the life of the filament, but made a more brilliant and efficient lamp. This is the nitrogen-filled lamp, now so commonly used when very bright lights are desired.

Electric lamps differ in many ways. Although the filament is almost always made of tungsten, we occasionally find a lamp which still uses the Edison carbon filament. Some lamps operate on low pressure and some on high. The pressures range all the way from a 1 volt lamp to 220 volts. The intensity of illumination may also vary. In the home we use lamps that consume electrical energy at the rate of from 10 watts to 60 watts. Advertising signs often use 75-watt lamps, and projection lanterns employ lamps whose rate of energy consumption ranges from 100 to 1,000 watts. Lamps may also differ in shape and in color. The glass of the globe may be frosted, clear, or colored. The lamp sockets, too, are varied. The "minature" socket is used for flashlights, the "standard" socket for the home, and the "mogul" size is used in certain kinds of projection lanterns. The automobile uses a still different socket. Here the socket is a smooth brass collar which slips into place and is held fast by a pin in a groove.



The diagram above will give you a glimpse inside your flashlight. Usually two dry cells provide the electrical energy. Since each cell furnishes electrical pressure of 1½ volts and the cells are connected in series, the total pressure is 3 volts. The button at point A slides up and down. In the picture at the left the light is "off" because the contact is not made. At the right, the button has been pushed to the "on" position and it makes contact at point B. With the circuit completed, the electrons can flow to the filament in the lamp, and the filament then grows hot enough to glow. The reflector and the lens help to concentrate the light and to cast it forward in a narrow beam.

Heat, light, and power are the three things which electric companies sell to the public. Power, in this case, refers to mechanical force. It means that anyone who wishes to turn machinery, lift and lower elevators, or drive subway trains and trolley cars, may draw upon the flow of electrons for any of these purposes. The device employed is the electric motor.

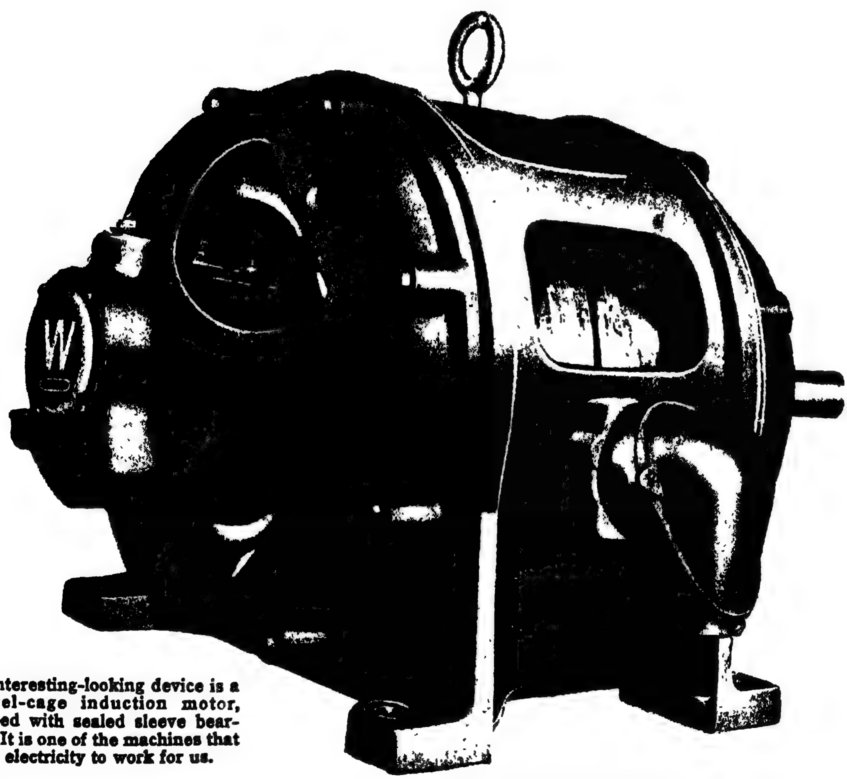
How is such a motor constructed and how does it act? In the first place, a motor is built exactly like a dynamo, about which we have already learned. It consists of a stationary field coil, a movable armature, brushes, and commutator. In fact, a motor may be used as a dynamo and a dynamo as a motor. Turn the armature so as to generate a flow of current, and it is a dynamo. Supply it with current so that it will turn, and it is an electric motor.

To make the simplest kind of electric motor, one may balance a magnetic compass needle on a pivot and bring the north end of a bar magnet near the north end of the compass needle. The latter is repelled and moves away. As the south end moves into the place formerly occupied by the north end, twist the bar magnet around so that its south end is now near the needle's south end. Again there is repulsion and the compass needle keeps on rotating. Continue the

procedure, always presenting north to north and south to south. The compass needle spins like a motor.

The action of a motor resembles that of the two magnets described above. The field coil and the armature interact in such a way that opposite poles are always near each other. The continued repulsion causes rotation. The commutator and the brushes, by always carrying the current to the armature coils when they are in certain positions, bring north ends and south ends constantly together. Thus continuous rotation is assured.

The electric motor is an essential to modern life. In the home we have vacuum cleaners, electric fans, washing machines, sewing machines, phonographs, electric driers and refrigerators, all driven by electric motors. In city streets we see striking electric signs that perform all sorts of tricks with the aid of spinning motors. Escalators and hoists, derricks and cranes, printing presses and linotypes, grindstones and polishers, lathes and drills, pumps and presses—all depend upon the electric motor for their power. And when we want to move about from place to place, the motor again serves our needs. No automobile can start without it; skyscrapers depend upon it for lifting and lowering their elevators; and trolleys and subways use electric motors in transporting their millions of passengers. Even railroads are slowly but surely discarding the steam locomotive in favor of the power which two interacting electromagnets can supply.



This interesting-looking device is a squirrel-cage induction motor, equipped with sealed sleeve bearings. It is one of the machines that put electricity to work for us.

Photo by Westinghouse Electric Co.

CHEMISTRY

Reading Unit No. 1

WHAT IS AN "ELEMENT"?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

Democritus' theory of matter, 1–532
What is an element? 1–534
How many elements are there? 1–535
What things are not elements? 1–535-36
Compounds, 1–536
Rare metals, 1–536-37
The most common elements, 1–537
The commonest gas, 1–537-38

Things to Think About

How was air shown to be a mixture of different substances?
How does chemistry save us millions of dollars on our electric light bills?
Of what use is nitrogen?
What is the difference between an element and a compound?

Picture Hunt

Describe the laboratory of an alchemist, 1–532
What are the different forms of matter? 1–534
How is nitrogen put into the soil? 1–537

Related Material

How are dyes made? 9–304-7
How are chemicals obtained from salt water? 1–557
How is water broken up into its elements? 1–364
How is iron taken from its ore? 9–400
How has radium helped man? 1–283
How is copper obtained from its ore? 9–416
How are chemical fertilizers used to help farmers? 9–153
How does chemistry help in photography? 10–450-51
What are the elements? 1–551

Practical Applications

How has steel been improved by chemists? 1–536
How are light yet strong machine parts made to-day? 1–536

Leisure-time Activities

PROJECT NO. 1: Make some gas from coal, 1–534.
PROJECT NO. 2: Fertilize some soil by ploughing under some clover or peas which you have grown in it, 1–537-38.

Summary Statement

An element is a substance which cannot be broken up into simpler substances by chemical means.

Photo by Chemistry Magazine

This relief shows Art and Knowledge. In the distance is the Temple of Learning, against the foundations of which the sea of Ignorance dashes vainly. Mankind, represented by an old man seated upon a sphinx, is probing the mysteries of the unknown under the guidance of Science, the tall figure in the center, who has just removed the blindfold from his eyes. Art is writing down the new revelations.

WHAT IS *an* "ELEMENT"?

This Will Tell You about the Building Bricks That Go to Make Up Everything Our Physical Universe Contains

HAVE you ever stopped to think what things are really made of? If you have, are you still rather mystified? Can you say why a tree looks so different from a stone? Is the material that goes into them very different, or is it possibly the same material shaped in different ways?

Now we are going to try to answer those questions, but no very simple answer to them can be given. It has taken us many centuries to find out the answers we now know. And the answers to such questions make up the science of chemistry.

Let us ask a few more of these questions. You have a number of friends, and you know each one by a separate name—the names bring to your mind different appearances perhaps. John may have red hair and blue eyes, Mary blonde hair and blue eyes, and Tom dark hair. Or you may picture them by "temperament." John has a fiery temper, but is very friendly; Mary is very quiet, but does not make friends easily. Yet do you believe that your friends are unlike because they are all made of different things? Is it not more likely that they are made of the same things, but are fashioned in different ways? You would possibly say that Bill is jolly because he is fat—or fat because he is jolly—meaning that Bill is jolly just because there is more of him, not that he is made of different material!

That may all be very well for people, you will say, but when we turn to non-living, or "inorganic" (ĭn′ŏr-găn′ĭk), things the case is different. Some stones are plainly made of sand grains stuck together; others have no grains visible. If we put a very biting liquid known as acid on a sandstone nothing happens, but if we put it on a fine-grained rock known as limestone or marble, we can see and hear a bubbling and fizzing where

the acid touches the rock. The two stones must be made of different things, because the size would have nothing to do with the fact that the acid "attacks" the stone in one case and not in the other. And you do not really think that mud and steel are the same things, do you? Do you believe that a lot of mud, or any mud made into some special shape, would be the same as steel? Or that you can turn steel into mud by grinding it up or doing anything else to it? No, almost all of us think that many things have different kinds of particles and that one kind of particle, when present in large numbers, gives us what we know as steel, another gives us marble, and another the salt we eat in our food. We shall have to see if we cannot limit the number of different kinds of material, however; if the number is without limit it must have very serious consequences for man.

The Greek philosophers were perhaps the greatest thinkers the world has ever known. They gave reason the highest place among the endowments of man. In their theories about the way in which the universe obeyed unchanging laws, they sought to prove these laws by sheer reason, rather than by scientific experiment. To-day scientists prefer that physical laws should be drawn from observed experiments.

For what man is trying to do is to simplify all the things in nature, and to classify them; that is, to put all the things of one kind together so that he may more easily hold them in his mind. Suppose that each individual thing in the universe were to be "a law unto itself," and like no other thing in the universe. Then there would be no use in our studying the inorganic world, for each time we touched or saw some object it would be strange and new. And we could never hope to learn all objects in the universe, for their number is far too great. Ever since man began to reason about the world, he has been searching for some way to group things together—some way to find a true relationship between all the objects in nature. His ideas of these things have changed greatly since he began to think about them.

Some of the early thinkers did actually believe that no two things in the universe were related. They taught that nothing could be learned from studying the things around us, and that man should cease to worry about them, and should, instead, improve his mind by thinking about himself. A more general belief, but leading to the same end, was one which held that all things will remain just the same, no matter how finely you divide them. A piece of iron cut into smaller and smaller pieces will still be iron, and look like iron. A piece of wood will be no different from wood even though it be divided forever and ever. Under such a theory it was felt to be useless to study things, because we should never find anything new; we could see the real nature of a thing right on the surface.

Still another theory held sway for many centuries. It was that all matter is made from four "elements"—fire, earth, air, and water. If two stones differed it was because one contained more earth than the other, or did not contain so much water. The fire in a thing was thought to be dry and warm, the earth dry and cold, air warm and moist, and the water moist and cold. It was possible to judge the contents of a thing by touching it, since its "dryness" or "moistness" or "coldness" could be found out in that way. A burning stick gave evidence that it contained all four elements: fire was shown by the leaping flames; water could be seen in

Photo by Deutsches Museum

The alchemist's laboratory was hidden away in some gloomy cellar like the one above. Here he carried out his strange experiments – mixing and heating various substances in the hope of finding a recipe for making gold. In the picture above you may see the great hearths where he heated his materials. Strewn about are vessels for heating, mixing, and distilling. The absence of light made the place look very mysterious indeed. A collection of stuffed animals and herbs that were supposed to work magic must have added more mystery. No wonder simple people thought that the alchemists must be in league with the devil!

the drops appearing at the end of the stick; air appeared as the warm and moist steam; and the ashes left after burning resemble earth. Some men even went so far as to try to change one material into another by driving off the water or air they thought to be in it—because on their theory such a change would be quite possible. Such attempts always failed, and yet the "four-element" theory, or parts of it, lasted until just a few centuries ago.

The Theory of Democritus

Meanwhile another theory had risen, flourished for a while, and then had been almost forgotten for hundreds of years. Democritus (dē-mŏk'rĭ-tŭs), one of the Greek philosophers, was the man who first gave it to the world. He believed that if anything could be divided again and again, down to particles that barely could be seen, and then in imagination divided many more times, one would finally reach very small particles which could not be divided any further. Democritus called these imaginary particles "atoms" (ăt'ŭm)—the name meaning "that which cannot be cut." He thought of these atoms as little balls made of a very hard material. Everything in the universe was understood to be composed of atoms. But then Democritus had to explain how there were so many different things in the world if his atoms were all alike. He and his followers probably thought they gave a very good explanation. To-day we might find their tales confusing and meaningless. But even though the "atomists" did not do very well in making the world of their time any clearer to their fellow men, they did bring a new thought into the study of the universe—a thought which time has proved to be much closer to the truth than any of the other theories of that day.

The Kinds of Atoms in Nature

For the modern chemist is himself an "atomist," though he does not believe exactly what Democritus and his school

Photo ' · Itechgitz

Faraday is best known for the fundamental work he did in the field of electricity. But he started out as a chemist's assistant—in fact his first job was to wash glassware in a chemist's laboratory. Later he studied the chemistry of batteries, and this led him to the study of electricity. Both sciences were still in their infancy in those days. As you can see from his laboratory, above, Faraday had practically none of the complicated apparatus you would expect to find in the laboratory of a modern scientist.

held to be true. Only during the last hundred years have we been able to go beyond the Greek philosophers and to say that we really know something about these very small particles which make up everything. We are no longer guessing when we say that instead of one kind of atom there are ninety-six in all nature, and that, strangely enough, four of them have been made by man himself. We know, also, that what we call atoms are not hard, little balls, but are almost little universes, with tiny parts that are like stars, planets, and even comets.

The Greek Idea of an Element

Many of the Greeks and Romans believed that all things were made from the four "elements"—fire, earth, air, and water. The word "element" meant to them that there was nothing more simple than these four elements. No one thought that air or water might itself be made up of still more simple things, and certainly no one sought to find out by actual trying or testing. Indeed, it was not until about the time of the American Revolution that air was found to be made of more than one thing. This is how it was done:

How to Break Up Air

A bit of tin was put into a tightly closed vessel filled with air, and all was heated over a hot fire Part of the air combined with the tin. This could be told from the change in the appearance of the tin and from the fact that when the vessel was opened after heating, air rushed in violently. But no matter how much tin was used, not all the air in the flask could be made to combine with it. So it was correctly guessed that the air had at least two things in it, one of which would join with the tin and one of which would not. This discovery marked the beginning of the end for the old "four-element" theory, because it showed that air itself was made of other things. Later it was found that by passing an electric current through water, two gases, like air, could be obtained at the

same time that water was destroyed. In this way water was shown to be made of two gases, and not to be a simple thing which, with fire, earth, and air, helped to form all the objects in nature. To-day the chemist knows that all these four things are made of other things, and he would not be content to call them elements. He has a special meaning for that word, and a very different one from that given to it by the Greeks and Romans.

An element to the chemist to-day means a substance which contains but one kind of matter. We can do a large number of things to a substance to find out what it is made of. Two of these things we have just been mentioning, when we spoke of using heated tin to separate off one part of the air, and of passing an electric current through water to break it up into two gases. A great many substances will give up two or more kinds of matter when they are heated. One of these is a red, heavy powder. When heated, it gives off oxygen, the gas in the air which supports life; while the part left over is the ordinary quicksilver, or mercury, such as we use in thermometers. Or we can treat things with acids which destroy many kinds of metals, stones, and living animals and plants. In the process of destruction we may find that the metal or stone had a great many different materials making it up. The blade of your penknife is almost pure iron, but a little bit of certain other substances has been added to make it harder. The white stone which forms your front steps or decorates your home is marble, and it is made of three kinds of things closely joined together. Now are all things like that? Are all the substances in the world built of still other things? The chemist answers that there are certain simple substances which contain only one kind of matter. These substances are his "elements," and a number of them are familiar to us all.

[illegible] Zion National Park, and American Gas Ass'n.

Anyone knows that rock is a solid and that water is a liquid. Liquids and solids are everyday things to us; but with gases it is another story, for there are so many that we cannot see. In the picture in the center, for example, a clay pipe has been stuffed with coal one of the solids we are all so familiar with. As the pipe is heated over a flame, the coal gives off a gas that is quite invisible. In this case it has been lighted, and you can see its tiny flame at the end of the pipe stem.

You are familiar with a good many metals. You have seen copper in wires and pennies, iron in any number of things besides your penknife, lead in bullets and weights for fishing lines, aluminum in pots and pans, and mercury every time you have looked to see how cold the weather was. Gold, silver, and platinum are known to everyone, and the delight of owning silver may be enjoyed by anyone with a dime. Tin, zinc, nickel, and chromium (krō'mĭ-ŭm) are not so common in familiar objects, but if you have read our stories about the various metals you know all about the uses of these and many other metals.

Even if you have seen these metals many times you may not yet know that they are all elements. Gold, for example, cannot be made to give us anything but gold, no matter what we do with it. We can heat it, put it into acids, freeze it, or hammer it out until we can see through it, and still it is gold, nothing but gold. We cannot get any gases from it, and whatever we do to it we can always bring it back to the original gold. This does not mean that gold will not combine with other elements, for it will. In that case it may lose its character or appearance of gold altogether. In fact it is no

longer gold, but is now helping to make up some substance which is not an element; but if we know how, we can get back from this substance our gold and any other element or elements which have been combined with it. No matter what is done to the gold itself, no one has ever obtained anything but gold from it. The same thing is true of our other metals, for they are "elements," and any element contains but one kind of matter.

We have now named twelve elements, all of them metals. Chemists know that there are ninety-two elements occurring naturally in the universe and making up all the things in it. So we have eighty more to learn about. The thing is not so simple as it used to be for the ancients, who had only four elements to remember. But few people now try to remember the names of all the elements. Some of them are so rare, indeed, that only one or two chemists have ever seen them. Above all, we now have certain ways of grouping the elements in order to make them easier to study and remember. In this story we shall not have to worry about more than a dozen or so additional elements, and then we shall see how the chemists group the others with these well-known ones in order to deal with all of them more easily.

Here is Thomas A. Edison visiting the research laboratories of a great electrical company. Dr. Langmuir, one of the Nobel prize winners, is showing him a 30,000-watt gas-filled tungsten filament lamp that he has made for experimental purposes.

How the Chemist Classes Things

How would you start to group all the things in the world if you were asked to do so? Perhaps you would say that the two most important groups are the living and the non-living, and many people would agree with you in that. Then you might try to divide the living things into animals and plants, and the non-living ones into stones, metals, and other classes. But if you were to ask a chemist to divide things up for you, he would probably say that it makes no difference whether it be living or non-living.

The chemist would first class all things as elements or not-elements, and the not-elements would have to be substances made up of two or more elements combined. After that he would probably want to know whether a thing is a solid, a liquid, or a gas. In one of our stories about physics we have said that a solid is a firm substance which does not change its shape readily, while a liquid, such as water, takes the shape of the container which holds it, and a gas may swell and swell in size until it fills any container, no matter how large. Although this division into three classes is not very important—since many solids can be changed to liquids or gases by heating, and liquids or gases to solids by freezing—it helps our memory in studying the elements. We know that these ninety-two kinds of matter are almost three-fourths solids, such as the metals we have described. About one fourth are gases, and only two are liquids at the ordinary temperature of a room.

Let us now look at a few more of the elements among the solids.

Have you ever been dazzled by some of the fireworks which you lighted at night? The brilliant light given out by many of the "candles" and "torches" blinds you for a moment to the other things about you. Or have you been in a room where a flashlight picture was being taken? Did you blink in the picture, from the blinding flash?

You know that many kinds of fireworks have powder in them. But the powder is used only to start them, and the brilliant light does not come from the burning gunpowder. It comes from a finely ground metal named magnesium (măg-nē'shĭ-ŭm). This magnesium powder also furnishes many photographers with light for taking indoor or night pictures. The metal, when pure, is a silvery gray, and it is much lighter in

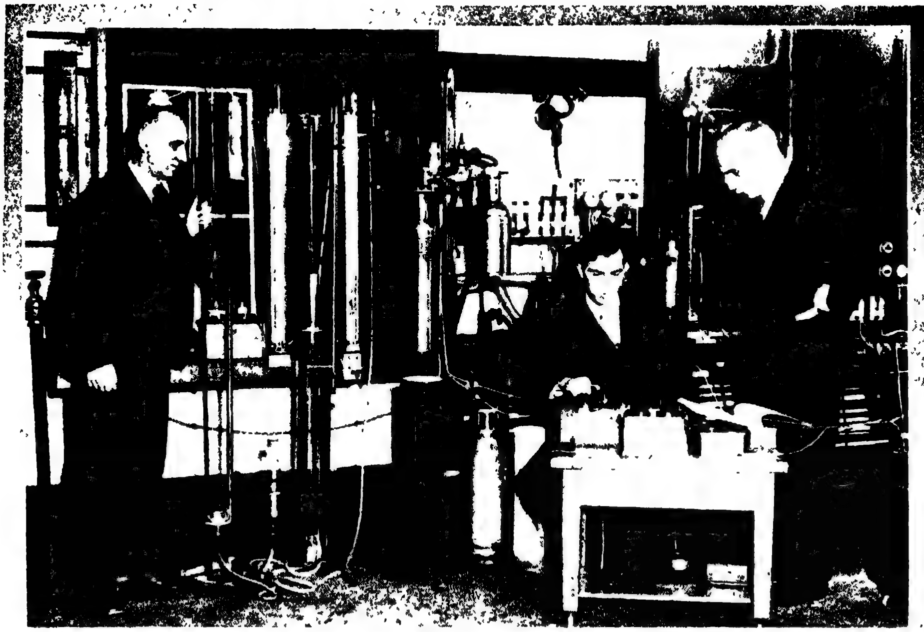


Photo by International News Photos

We have come a long way from the thinking but unexperimental Greeks and from the alchemists and their "witchcraft." Above is a modern laboratory where you may see the complicated apparatus which scientists use to liquefy some of the rare gases of the air. They are busy liquefying helium.

weight than are the precious metals. It is not found pure in nature because it combines very easily with other elements to form many "compounds," of which Epsom salt is perhaps the most common. Even little chips or ribbons of magnesium will burn rapidly if ignited with a match, but if the metal is melted and fused into an alloy with certain metals, especially aluminum, a lasting product of great strength and lightness will result. These features give such an alloy wide use in the manufacture of airplanes, artificial limbs, moving-picture machines, and in many other things where light weight is required. Our magnesium comes from the United States, largely as a "by-product" in obtaining salt.

An Important Use of Tungsten

Tungsten is the other metal, a very heavy one, which helps to make the world a brighter place. It has two very important uses: one for the fine wires or "filaments" in electric light bulbs, and the other for making tungsten steel—a steel made extremely hard by adding about one-sixth of tungsten. You can probably remember some of the old "carbon" light bulbs, which gave a rather sickly, yellowish light. They were used before our modern bulbs, with tungsten filaments, were invented. These newer bulbs give us a much stronger light, and at a smaller cost; it is said that in the United States we save $2,000,000,000 a year by the use of tungsten in electric bulbs.

The Value of Tungsten Steel

The use of tungsten in steel is almost as important. Tungsten steel has the great advantage of not losing its "temper"; that is, it can get extremely hot without having the cutting edge or point dull quickly. Therefore the machinist does not have to wait for the tool to cool off; and one automobile maker says that this one fact saves fifty dollars in the building of a single car.

The greater part of our tungsten now comes from our own country, though before the World War all of it was imported from China, the country which has the

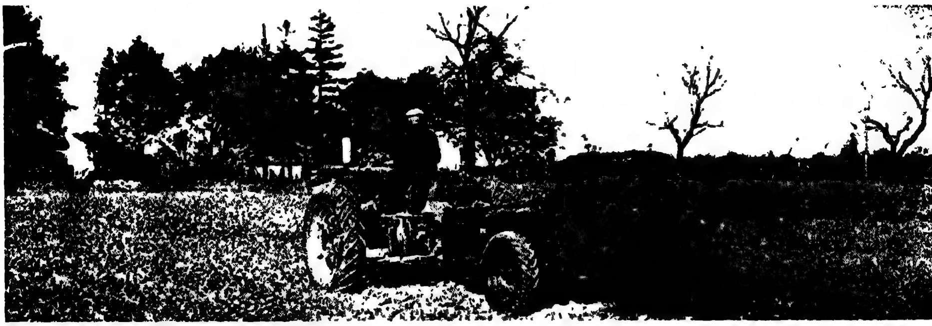


Photo by International Harvester Co.

This tractor is pulling a fluid manure spreader which is putting nitrogen back into the soil, so that rich crops will grow. The manure is made from animal remains and is replacing the nitrogen that crops which grew there before took away from the soil. Nitrogen may also be added in the form of chemicals called nitrates.

largest supplies of the metal. Only about one hundred tons a year are needed for all the electric bulbs made in the United States, so fine is the wire used in their manufacture.

One of the World's Most Common Elements

There is a very good chance that you cannot give the name of the most common element to be seen on the surface of the earth. The element is silicon (sĭl'ĭ-kŏn); and if the name is not familiar it may be because the element is never found in the pure state, but is always joined or combined with other elements—usually with oxygen from the air. This compound of silicon and oxygen is called "silica" (sĭl'ĭ-kȧ), and you know it very well. Another name for it is "quartz," and still another is "rock crystal"; but the commonest form is just "sand." Our sand beaches are storehouses of silicon, though it is always combined with the element oxygen. We do not have to worry about separating it, however, for we use the sand as it is for a great many things. You have seen sand and pebbles—and the greater part of the pebbles is silica, too—used in making concrete and mortar, and in the finished concrete you can see or feel the sand grains. In glass, made from the same material, the sand is melted and then allowed to become solid again, and in this process all traces of the grains are lost. Quartz is also made into fine glass. It is possibly because silica is so common and so plentiful that we talk so little about it. If it were scarce, our glass would be very costly; and then we should surely be asking about the stuff from which it was made!

Physicists (fĭz'ĭ-sĭst) tell us that gases are much like liquids, except that the particles of a gas are free to move about without hindrance from their neighbors. We may compare the particles of a liquid to a crowd of people jammed so tightly into a street car that they hold each other in position, so that no one of them can move unless the whole crowd does so. They do, however, fit themselves into every corner and space of the car, just as a liquid does in its containing vessel. If we heat a liquid until it turns into a gas, the particles become much more free than they were before, and they can fly off to any distance, and need never return. They are like the people who leave the crowded street car; they are now at liberty to move in any direction they wish, and their neighbors no longer hinder them.

The Commonest of the Gases

Some of our elements, unlike gold and silver and copper, are everywhere on the surface of the earth. They are the gases of the air. Our stories about physics will tell you all about the air and its character—how it is made up of a mixture of a number of gases, how sound is carried through it, and how it keeps us from losing all the heat of the earth and freezing to death. But the chemist is interested above all in what the particles of gases in the air do, what they combine with, and how we may use them.

Oxygen is one of the gases we know best.

Many times we have been told to go out into the fresh air and "get some oxygen in our lungs," for it is the gas which supports life. You all know how it is taken into the lungs, passes into the blood, and then is carried to all parts of the body. It is necessary to the body in order that there may be enough actual burning there to provide us with the heat we need.

How We Take in Nitrogen

Nitrogen (nī'trô-jĕn) is another gas in the air. It is present in much greater amounts than is oxygen, though we do not hear of it so often. It is just as important for us as is oxygen, but we do not take it in directly from the air. We get nitrogen from the meats or vegetables we eat, and they in turn get it in a very odd sort of way. All animals get it from plants, or from other animals which have taken it from plants; while the plants, which need it to live, get it generally from the soil, where there are compounds containing nitrogen.

After several crops of plants have grown in one place, then, you might expect that they would have taken about all of these nitrogen compounds out of the soil. And for many years, indeed, farmers have known that their soils would grow poor—that is, would lose their nitrogen—unless fertilizer were spread on the ground, or unless a crop of clover, peas, or beans were grown on it. The farmers wondered what it was that the clover put back into the soil. Almost a century ago it was found that in the rootlets of these few plants there lived a host of bacteria (băk-tē'rĭ-â), or microscopic plants, and that these bacteria were of a special kind that could take nitrogen from the air and make from it compounds that the plants could use. So that is how the nitrogen gets into the soil and is taken up by plants. Then an animal eats the plants, and the nitrogen is used to build up the flesh and bone of the animal. At the death of the animal, its remains usually go back into the ground, and the nitrogen passes once more into the soil, there to nourish plants again. The "cycle of nitrogen" is a name often given to this traveling and returning to the same place; now an atom of nitrogen may be in a plant, next in an animal, next in the soil, and then back in a plant again, completing the "cycle." Some little bit of the gas is lost at each change, so that we still have to use fertilizers, which contain nitrogen, in many parts of the world.

We have mentioned a gas that we breathe and another that we eat. Now for two gases that we drink! For every day every one of us drinks some of a certain liquid that is made up of two gases. That liquid is plain water, and all water is made out of the two elements of oxygen and hydrogen (hī'drô-jĕn).

Oxygen we have already met. Hydrogen is the lightest thing in the universe—so light that it was used for many years in filling balloons. So far as we can tell by our senses, it is otherwise quite similar to oxygen, in that it has no smell or taste, and is invisible. Yet these two gases combine to form one of the most common and necessary things on earth!

Our two liquid elements are by no means so important for us as water. One of them is mercury, or ordinary quicksilver. It finds use in thermometers and barometers for measuring the temperature and pressure of the air, for making mirrors, and in several types of electrical machines. Some of the compounds of this liquid find important uses in medicine. Almost all of the world's supply of this element comes from Spain and Italy.

A Poisonous Liquid Element

Bromine (brō'mĭn) is the other liquid element. It is a foul-smelling, reddish liquid which is poisonous if it is breathed into the lungs or if it comes in contact with the skin. It also attacks the eyes of those exposed to it. Little wonder, then, that you are not familiar with this liquid!

We have now found out a good deal about the elements, but we still have many questions left to ask. For the answer to these questions we must go on to the next story about chemistry; and there we shall find that these questions will bring up several others.

CHEMISTRY

Reading Unit No. 2

WHAT IS AN ATOM, AND A MOLECULE?

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The ancient Greek idea of the atom, 1–540-41
What does an atom contain? 1–541
How may atoms combine? 1–543-45
What is a molecule? 1–544
How may certain compounds be formed? 1–545
Inactive elements, 1–547-48
What determines the character of an element? 1–548

Things to Think About

How are the kinds of electric charges in an atom balanced?
Do all atoms possess the same total electrical charge?
How do electrons affect the combination of elements into compounds?
How may atoms lose electrons?

Picture Hunt

How may atoms be smashed? 1–546
What is believed to be the structure of the simplest atom? 1–541
What is believed to be the structure of fluorine, sodium, and oxygen? 1–543-44

Related Material

How is neon used for illumination? 1–377, 10–392
How has neon been used in television? 10–125
How is helium used to make airships safe? 1–375, 377, 473, 547, 10–315
What is the effect of the salt of the sea upon rocks? 1–70
What are the sources of salt? 1–44, 3–74, 76
How do electrons give us electric current? 1–496, 499
How is chlorine used to kill germs? 10–553
What part does calcium play in our bodies? 2–315, 320-21

Practical Applications

What are the uses of rare gases? 1–547
What is the most common use for aluminum? 1–547

Leisure-time Activities

PROJECT NO. 1: Make models of atoms, 1–543-44.
PROJECT NO. 2: Make a collection of common elements, 1–551, 554.

Summary Statement

Atoms are made up of small bits of electricity called electrons and protons. Their arrangement is what determines the element.

Photo by Keystone View Co.

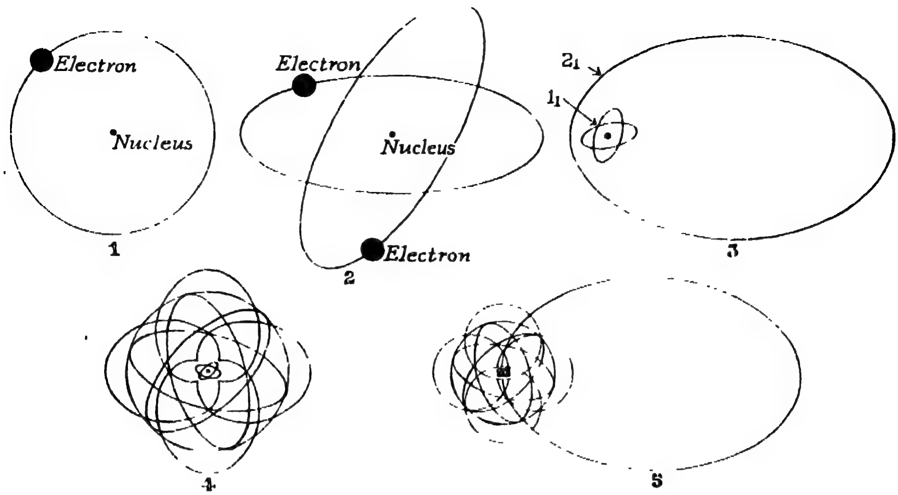
The word "atom" means "something that cannot be divided," for the Greeks, who first thought of atoms and named them, believed that these tiny particles could never be torn apart. But experimenters in the Cavendish Laboratory in Cambridge, England, succeeded some time ago in breaking the atom into tiny parts. Dr. Cockroft, who is performing a similar experiment in the picture above, cannot see the atom, of course, but he can hear its disintegration. That is to say, when the atom is broken apart, it sets up a tiny current which, when greatly magnified, can be heard through the ear phones he is wearing.

WHAT IS *an* ATOM, *and a* MOLECULE?

How the Tiniest Parts of an Element Join in Bunches Clinging Firmly Together

CERTAIN of the Greeks believed that all things were made of very tiny hard balls which they called "atoms." They really had no great reason for this belief, but in those times men often did not seek for what we should call proof in these matters. The Greeks hardly tried to find out by testing or experiment whether their ideas about the atoms were true or false. We need not blame them for this failure, for even to-day we are only too likely to accept many things as being true without any experimental reason for believing them. Until a few hundred years ago the doctors considered it beneath their dignity, and indeed wholly unnecessary, to study the human body. They *knew* from the guesses of those before them what the body *must* be like, and why waste time studying something already known? The chemists, during that same period, bent their energies in one direction—to change other substances into gold—and they had little time for finding out whether or not things were made of atoms. They wanted gold, not theories!

So the atom theory of the Greeks and Romans was forgotten for centuries, and not until a large number of facts about things had been gathered was it brought forth again, polished up, and presented to the world with reasons and proofs of such force and clearness that it was generally accepted. This was somewhat more than a hundred years ago.



No. 1 in our diagram shows the simplest atom, hydrogen, with but one electron revolving about the nucleus. No. 2, the helium atom, has two electrons revolving about the nucleus. Its shell is therefore complete, for, as we have said in this article, there can be no more than two electrons in the first shell. If another electron is added, it must start a second shell. No. 3, the lithium atom, has three electrons—and so two must be in its first shell and the third in an outer shell. If we add seven more electrons to this outer shell we shall have the neon atom at No. 4. No more than eight electrons can go into the second shell, as we have said; so when we come to the sodium atom at No. 5, which has eleven electrons, we find—what? It is very simple to figure out: there are two electrons in the first shell, as in the helium atom; eight in the second shell, as in the neon atom; and the last electron starts a third shell still farther from the nucleus. Atoms do not look like this, of course. Our diagram is only to help us understand what the scientist works out by mathematics. On another page you will find a set of atoms that look quite different.

Even about the beginning of our own century, an atom was still regarded as an indivisible little particle. It was the smallest unit of matter, and nothing smaller was thought possible. Then radium was found, and the startling fact was discovered that this element was always exploding and forming several other well-known elements in the process. The meaning of this "disintegration" (dĭs-ĭn′tĕ-grā′shŭn) of radium can be learned from our article on that substance. Here we are interested especially in this fact: that in the disintegration of radium there are shot out from the atom a number of particles of at least two different kinds—which is to say that the atom of radium is itself composed of still smaller things! For that reason we have departed from the Greek idea of atoms as hard, indivisible little balls, and have come gradually to think of them as things more complicated than the solar system—for we know now that atoms of various kinds are made of from two to as many as several hundred "parts." What these "parts" are we shall now discuss.

We are told that the atom—any atom—contains a central part called the "nucleus" (nū′klē-ŭs). Now you must not imagine that even the nucleus is like a little ball, or like our sun in the center of the solar system. The nucleus is not nearly so definite and sharply outlined, because it is made of—what do you think?—electric charges! "But," you say, "I cannot imagine what electric charges look like. I can remember a little about positive and negative charges, and I know they can be made by rubbing things like silk and hard rubber together. But I'm sure I never saw an electric charge in my life." Quite so, and neither has anybody else ever been able to see these charges, even in his imagination. In our diagrams, the best we can do is to show the nucleus as a sort of ball in the center of the atom. But we must remember, when we look at such pictures, that this center, or nucleus, is made up of electric charges alone.

Outside the nucleus are a number of negative charges called "electrons" (ē-lĕk′trŏn). We can think of these as revolving around the nucleus, more or less as the planets revolve around the sun, though that may be only a convenient way of picturing them. Some of our diagrams will show the electrons as tiny points whirling around the nucleus in the center. Other diagrams will show the electrons as though they were at rest instead of moving; and some of them are shown as placed at the corners of a cube. We do not know which picture is correct. Indeed, we are not quite sure that any of them is right.

The "Shells" in an Atom

You will see, in our first kind of diagram, that no two electrons follow exactly the same path. If you look closely you will see that two of the electrons have paths very close to the nucleus, in comparison with those beyond. No more electrons can be crowded so close to the nucleus. Then, farther out, any number of electrons up to eight may form another "shell"—similar to an onion skin—around the nucleus, and no more than these eight can be squeezed into this shell. The lithium (lĭth′ĭ-ŭm) atom shows only one electron in this second shell, the neon (nē′ŏn) atom shows the full number—eight. When more electrons are added they lie in a shell much farther out, as is shown for the eleventh electron of sodium (sō′dĭ-ŭm)—the one making the big path in our diagram. No more than eighteen can occupy this shell, in which we show only one electron. Additional shells may be present until the number of electrons whirling around the nucleus may be as many as ninety-six. Imagine, if you can, what a picture showing the paths of ninety-six swirling electrons would look like; our diagram shows eleven only!

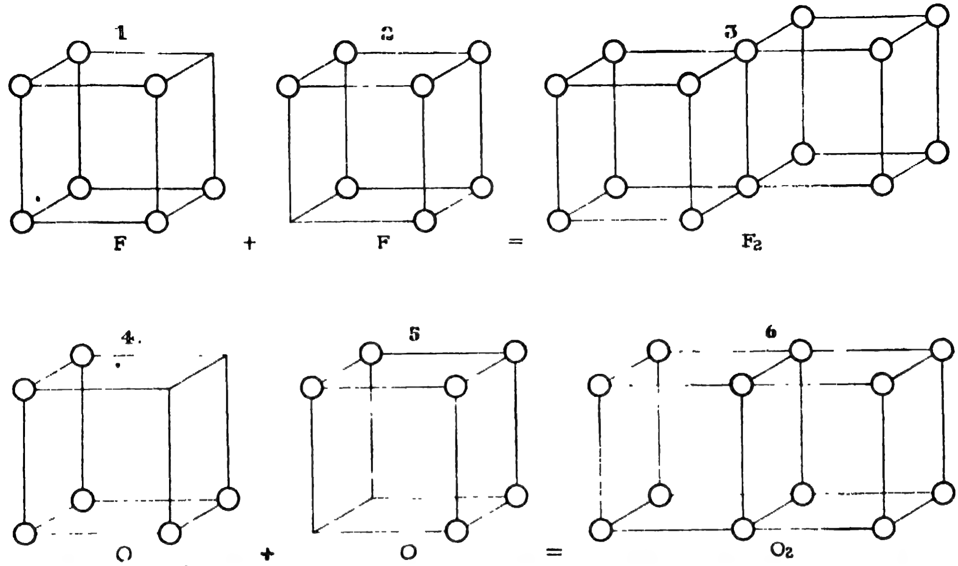
What is happening to the nucleus all this time? Does it remain the same while all these electrons are being added, shell by shell? The answer should be easy for those who know a little about positive and negative electric charges. A positive charge "neutralizes" a negative one. That is, if you take one of each kind and put them together, you have no charge at all left. If you have a charge on a hard rubber rod, the rod will attract little pieces of paper. But if there is added an equal charge of the opposite kind, the rod will no longer cause the paper to jump toward it. Since we know that the elements do not have a charge—gold or mercury or oxygen will not attract little bits of paper—we may be sure that there are just as many positive as negative charges in them. When we talk about an increase in the number of electrons, then, we must always remember that every time an electron is added a positive charge, or proton (prō′tŏn), must be added also. That is, a positive charge must be added in the nucleus to balance the negative charge of the electron; so that if we have five electrons outside the nucleus, there must be five protons in the nucleus.

The simplest atom of all is the hydrogen (hī′drō-jĕn) atom. It consists of but a single proton and an electron. Helium (hē′lĭ-ŭm), the atom that comes next in order of complication, has a nucleus containing two protons around which two electrons revolve. Lithium has three protons and three electrons; beryllium (bē-rĭl′ĭ-ŭm), four of each; boron (bō′rŏn), five; carbon, six; and so on through curium (kū′rĭ-ŭm), which has a nucleus containing ninety-six protons around which a cloud of ninety-six electrons revolve.

Numbering the Atoms

Atoms differ from one another in the number of electrons in the outer shells, and therefore they also differ in the number of protons in the nucleus. Scientists have assigned a number to all known atoms. The number tells us how many electrons revolve about the nucleus. This number is called the "atomic (ă-tŏm′ĭk) number." Thus hydrogen is atomic number 1; helium, atomic number 2; lithium, 3; beryllium, 4; boron, 5; carbon, 6; and so on. Every known element has its own atomic number. Including some of the recent man-made elements, there are elements with atomic numbers as high as 96.

These are facts which belong largely to the science of physics, for they do not tell us what the atoms do, but only how they are made up and what they look like. But

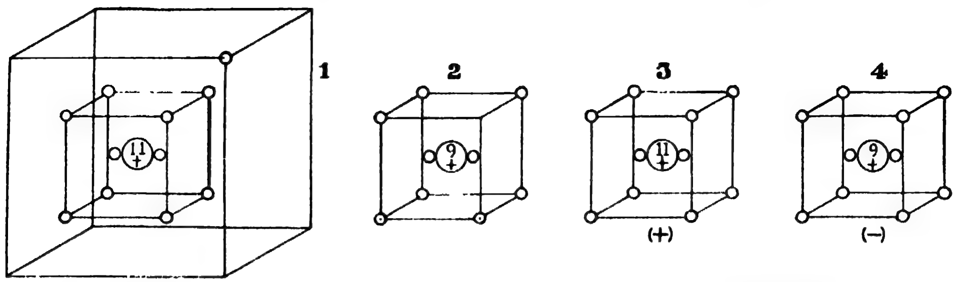


In this diagram you see the second shells of two rather simple atoms, fluorine and oxygen. We have left out the "insides" which would be, for each, a nucleus with its shell of two electrons. At 1 is the outer shell of a fluorine atom. We have pictured it as a cube with seven corners occupied by electrons and one that is vacant. As you will remember, eight is the complete number for this shell; so the fluorine atom is very eager to find a stray electron to fill its vacant corner. Often it has no trouble finding some other element which wants to give up, rather than gain, an electron. But if it cannot find one, it may combine with another atom of its own kind to form the molecule of fluorine gas shown at 3. Those two atoms of fluorine are really just sharing each others electrons. This arrangement seems to be quite satisfactory unless something better comes along. Then, if given a chance, the molecule of fluorine will split and each atom will take from some other element an electron which it may keep for its own and not have to share. Nos. 4 and 5 are oxygen atoms. No. 6 shows you how they may combine to form an oxygen molecule by sharing electrons. Atoms do not really look like this. Our diagram is just a convenient way of picturing them.

we have had to go over these facts because from them we can easily picture what happens when atoms combine to form molecules (mŏl′ĕ-kūl). And this leads to one of the most important facts in chemistry, simple though it may seem: one atom may lose one or more electrons. But when it has lost negative charges, it then has more positive than negative ones; and we say that the atom has a positive charge. A neighboring atom gains or adds to itself these lost electrons, thereby getting an extra number of negative charges; and we say that this atom has a negative charge. Now unlike charges attract each other, as any electrician knows, and the rule holds good in the atoms as elsewhere. And the two atoms, one positively and the other negatively charged, are attracted to each other and join together. That is how elements combine, for elements are nothing but large numbers of like atoms gathered together. A large number of gold atoms make a piece of gold as we know it. When gold combines with some other element, all the atoms of gold have an electric charge which they received through the loss or gain of electrons. The atoms of the element with which it combines have an opposite charge, and the two kinds of atoms — or the two elements — are held together by this attraction of opposite "kinds" of electricity.

What a Molecule Is Like

Have you begun to wonder whether there are two kinds of particles of matter? For at one time we talk about atoms of an element, and then we talk about molecules, perhaps of the same element. Or possibly you have the idea that a molecule is like a small stack or pyramid of cannon balls, each ball being an atom. Well, if you imagine such a stack of cannon balls heated so hot that they have begun to melt and fuse part



Sodium + *Fluorine* *Sodium Fluoride*
(Na) *(F)* *(NaF)*

This diagram shows how atoms of two elements combine to form a molecule of a compound. If you can understand it fully, you have learned most of our story of chemistry. No. 1 is an atom of sodium. In the center is the nucleus with eleven positive charges which just balance its eleven negative charges, or electrons. We have already seen on another page how these electrons are arranged in the shells about the nucleus. We know that, because of its eleventh electron which is all by itself in the outermost shell, the sodium atom is very eager to lose one electron. The fluorine atom, at No. 2, is, on the other hand, eager to gain an electron to fill its empty corner, although the nine positive charges of its nucleus just balance the nine negative charges of its nine electrons. So it is very natural that, when we place a sodium atom next a fluorine atom, the lonely electron of the sodium atom should go over to fill the empty corner of the fluorine atom. Nos. 3 and 4 look very much alike, but they have become ions; that is, their positive charges no longer balance heir negative charges count them and you will see why—so that one is now positive and the other negative. Particles with unlike charges will, of course, attract each other, and that explains why the two ions of sodium and fluorine are now held together, making a molecule of sodium fluoride.

way into one another, you will have a better picture of a molecule; for the atoms of a molecule are firmly bound to one another. In the air, for instance, there are molecules of oxygen and of nitrogen, and each of these molecules contains two atoms. Since it is very hard to split these two atoms apart, there must be some strong force holding them together.

Why Atoms Have Different Charges

We have explained before that the force holding atoms together is the attraction between opposite charges of electricity. And now we have to take back part of that statement, because it would lead us straight into trouble. In molecules made of the same kind of atoms, when one atom wants to lose an electron, all the atoms want to lose an electron! And if all the atoms do the same thing they will all have either a positive or a negative charge. Then, since "like charges repel," these atoms will avoid one another, instead of combining. So when we talk of atoms having different charges and being attracted to each other, we mean different kinds of atoms, or different elements.

When we have atoms of the same kind, or the same element, there is neither a loss nor a gain, but a sharing of electrons. You can imagine that an atom has a "blank" or hole in itself which it wants filled up. All the other atoms of that element have the same need, and they help each other by lending an electron to fill that hole. They do not, however, let the electron go. It is as if each atom said to another, "I will lend you one or two electrons to fill your blank spaces. I cannot let them go altogether; and in return you must lend me one or two to fill my empty spaces. The best way for us to help each other is to share electrons, so that neither one will really have to give anything up. Each of us will gain without losing." Our diagram shows how the elements fluorine (flōō'ŏr-ĭn) and oxygen form their molecules.

How Atoms Form Molecules

But what, you may ask, makes atoms combine in this way to form molecules? We have no opposite charges to bring them together, so we must look for something else. And the answer is one which helps to explain a great many things about which we still have to talk. It is another of our very important chemical theories:

When an atom has only the two innermost electrons—helium (hē'lĭ-ŭm) is our example—it is perfectly content to stay as it is. It does not even want to form molecules with its fellows. In atoms which have

more than these two electrons, whenever the outermost shell contains eight electrons, the atom behaves like helium. It is satisfied with its mode of life and refuses to have anything to do with other atoms either like or unlike itself. You can see how perfectly these eight electrons form the corners of a cube, and when all eight are present there is no need for any more; nor do any of the eight want to lose one of their neighbors. But when there are, let us say, only seven present, the structure is not complete. It is like a brick house which we have completed, roof and all, except for one corner that we have left unfinished, part of two walls and the roof being missing there. You can imagine that such a house would not be nearly so strong as a perfect one, and the same fact seems to be true for the atom. When it has only seven electrons, it is very anxious to gain an eighth one to finish its shell. When such an atom is among strangers, as we shall see in a moment, it can steal an electron from some atom which has one or two more than its eight, and which wants to get rid of the extra ones. But among its own kind, all the atoms possess only seven electrons, and they are all trying to find one more. Having no strange atoms to borrow from, they must now share what they have among themselves—and a very neat job they make of it, as our diagrams show. This is one way of completing an electron shell; the atom seems to be satisfied when there are two electrons in the inner shell and eight in the outermost shell.

The Secret of Compounds

In talking of molecules of one element only, we have practically given away the secret of the way in which unlike atoms combine to form molecules of "compounds." For molecules of a single element are really compounds, though since they are compounds formed of only one kind of atom, the chemist does not call them by that name. What he calls compounds are all formed of at least two different kinds of atoms. So compounds are really no mystery to us.

The secret is, of course, the loss and gain of electrons. One kind of atom will lose an electron and another kind will gain this lost electron. The two kinds, now having opposite electrical charges, will attract one another, and will combine to form molecules of a compound.

Why Elements Combine

You wonder how an element will combine with another when its atoms are already in the form of molecules? Well, the first element—let us say it is oxygen—is willing to share electrons so long as there are no electrons which it can have all to itself. But if another element comes near and offers an oxygen atom two electrons, that atom will bid farewell to its "molecule mate," saying, "So long as there was nothing better, I was satisfied to share electrons with you. But here is a stranger who is offering me two electrons to be all my own. I cannot refuse this offer—so good-bye!" And the oxygen molecule is split up to allow its two atoms to combine with the kind stranger.

When we are talking about large numbers of atoms, we may just say that one element combines with another to form a compound, because the atoms make up the element. So when we say that one element joins with another, we always understand that the atoms are really the things that do the joining. But not all elements join with all others. Some are said to be active, or to have "chemical affinity" (ă-fĭn'ĭ-tĭ), meaning that they will readily enter into combination with other elements. Others are said to be inactive, to lack chemical affinity, or to be "inert" (ĭn-ûrt'). That last word is usually reserved for those elements which will not combine at all—and whose atoms will not even form molecules of their own element. Sometimes two elements need only be brought together to combine. Others have to be heated or treated in some other manner before they will unite. The reason for the different behavior of the elements will be clear from a reading of our little chart which shows some of the elements arranged in rows and columns, in the order of the number of electrons they possess. Above the name is given its abbreviation; and below are the number of electrons in its first, second, third, and part of its fourth shell.

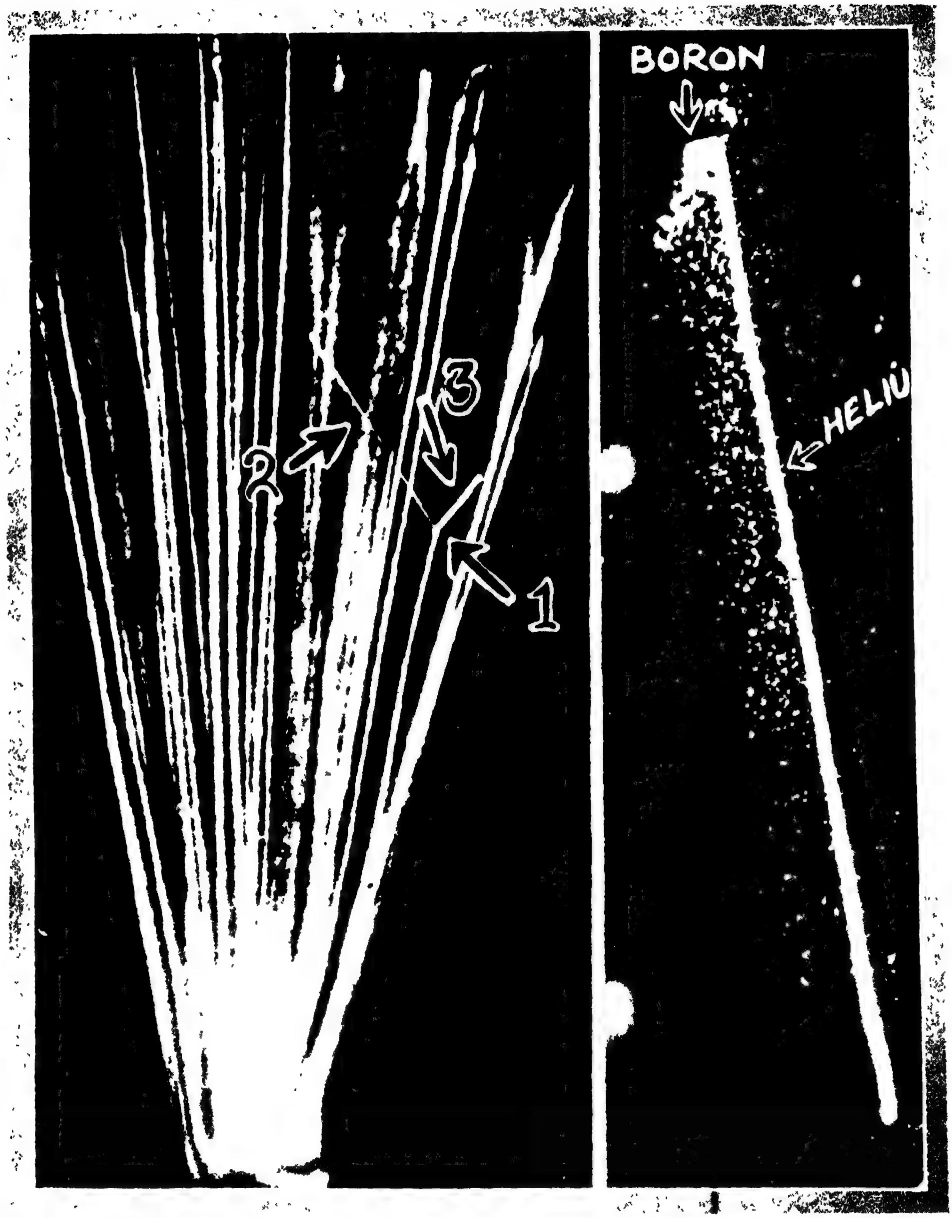


Photo by International News

Scientists have learned to explode atoms by shooting ions or other "particles" into them. They can follow the paths of the ions by a very ingenious device. The ions pass through air which is full of water vapor. They knock electrons off the atoms they pass through, converting the atoms into ions. The water vapor condenses on these ions, making little tracks of fog, a number of which you can see in the pictures above. Ordinarily the particles just blunder along, knocking electrons off atoms; but now and then one collides with the nucleus of an atom. Such a collision is likely to burst the nucleus into parts which fly off in different directions. At the left, 1 is the point of collision, and 2 and 3 show the paths of parts of the nucleus knocked out by the particle coming from the bottom of the picture. To the right we see another collision. Notice how abruptly the particle of helium is stopped by the nucleus of the boron atom it has hit.

H Hydrogen 1	He Helium (2) 0	Li Lithium (2) 1	Be Beryllium (2) 2	B Boron (2) 3	C Carbon (2) 4	N Nitrogen (2) 5	O Oxygen (2) 6	F Fluorine (2) 7
	Ne Neon (2) (8) 0	Na Sodium (2) (8) 1	Mg Magnesium (2) (8) 2	Al Aluminum (2) (8) 3	Si Silicon (2) (8) 4	P Phosphorus (2) (8) 5	S Sulphur (2) (8) 6	Cl Chlorine (2) (8) 7
	A Argon (2) (8) (8) 0	K Potassium (2) (8) (8) 1	Ca Calcium (2) (8) (8) 2					

The second column at the left contains three gases found in small quantities in the air. The atoms of all three have complete electron shells. The first, helium, has only two electrons, and these two complete the first shell. Helium, then, need neither gain nor lose electrons. We may say that it is "perfect." The other two gases, neon and argon, have eight electrons in the outer shell, and, of course, completed shells inside that outer one. So these gases, too, have no need for more electrons, nor do they have too many. These three are therefore the inert or "noble" gases—"noble" because they are "aloof" and will not combine with the other elements. Neon lamps give us our only familiar example of these gases or their uses. Helium is extensively used for filling large balloons and dirigibles because it lifts almost as well as hydrogen and will not catch fire

How Electrons Get Lost

The next column shows three elements—lithium, sodium, and potassium (pō-tăs'ĭ-ŭm) which all have one electron only in the outermost shell, the lithium having one in the second shell, the sodium one in the third shell, and the potassium one in the fourth shell. Now this one lonely electron, away from the rest of them, is very likely to be lost. It is not held firmly by the rest of the atom, as our diagram of sodium shows; and whenever a stranger searching for an electron comes near, an atom of this kind is most willing to give up its odd electron to the stranger. This is true for all three of these elements. The three elements are therefore alike in this respect. In fact, this willingness to lose an electron gives them a sort of chemical "character." We never, for example, find these elements in the pure state, because they cannot remain so in nature; they are too eager to give up an electron and so combine with some other element. They are all metals, light in color and weight, and so "active" that they will almost explode when thrown on water, so fast do they combine with it.

The next column contains three elements, which are also metals. These are beryllium, magnesium, and calcium (kăl'sĭ-ŭm). They are fairly active, since they can be persuaded to give up the two electrons of the outermost shell. Magnesium often combines to form the familiar Epsom salt, and calcium to form limestone, marble, and chalk. Neither of the three is found pure in nature.

Elements That Are Inactive

The three columns coming next may be grouped together, not because the elements in different groups are closely related, but because their outermost electron shells are neither nearly empty nor nearly full. We might say that these elements are somewhat inactive because they do not know whether to lose an electron or to gain one. You know the element aluminium, more commonly called "aluminum" from the many pots and pans made of it Apparently the aluminum in them does not want to join with anything. Carbon you know in the form of hard coal, in the lead of your pencil, and in the diamond. All of these are carbon. They are all inactive enough. Nitrogen, in the air, is perhaps next to the inert or noble gases in its inactivity. So we see that the elements with a half-completed outer shell are rather well satisfied to remain as they are.

The next to the last column contains the two elements oxygen and sulphur. These

two may be called fairly active elements, since they are willing but not eager to combine with a large number of other elements. Indeed, all the oxygen of our air would probably disappear into compounds if it were not being constantly renewed, largely by plants.

The last column brings us once more to the very active elements. You see that the two elements in it, fluorine and chlorine (klō'rĭn), have seven electrons in the outermost shell. They need only one to fill out the desired eight, and they strive mightily to obtain this electron. If atoms of other elements approach these, there will be a great tendency for the strange atoms to lose electrons, and they will do so, combining with one of these two elements unless their outer shells are quite firm. So chlorine and fluorine are not found as such in nature; they are much too active, as the use of chlorine in the war not many years ago clearly showed. This gas rapidly attacks the human throat and lungs.

The Importance of the Outer Shell

If we now look back over what we have learned about the way in which atoms combine to form molecules, we find that while trying to learn one thing we have found out at least one other thing which we had no intention of learning. We started out to say that atoms combine because one loses one or more electrons, getting a positive electric charge, while the other takes these electrons, receiving a negative charge. Opposite charges attract, and these atoms are held firmly together. In addition, we tried to explain *why* atoms sought to lose and gain electrons, or why certain elements are "active" and others "inert," and we found out that it is a question of the outer shell of electrons. If there are two for the first shell and eight for any other outer one, the atom is quite satisfied and inactive. If the outer shell is about half full, the atom seems to be undecided whether to lose or gain, and is not very eager to do either. But if the outer shell is just beginning, or is almost full, let us say—if it contains one or seven electrons—then the atom and the element are very active and are willing to lose to any atom, or gain from any atom, that comes near. In addition, we have found that if we have atoms of one kind only, they can fill out their shells by sharing electrons with other atoms of their own kind, forming such things as molecules of oxygen or nitrogen.

Grouping the Ninety-six Elements

So we have learned how the elements can be arranged in the sort of table we have put down, with the elements in each vertical column closely related to one another. Thus helium, neon, and argon are more like one another than they are like any other element in all the ninety-six. Lithium, sodium, and potassium are very closely related. The same thing is true in each of the columns given; fluorine and chlorine are as close to each other in their "character" as are helium and neon. And now we begin to see how the chemist groups his ninety-odd elements.

When chemists first arranged the elements in this way, they found that every now and then they had to skip a space in one of the columns in order to make related elements lie in the same column. They soon realized that this blank space was the place for an unknown element—one that had not yet been discovered! Since they knew the elements above and below that unknown one, they knew fairly well what it must be like. So they were able to predict just what the new element would look like, how it would act, how much it would weigh, and just where one would be most likely to find it! Searches in the compounds where its related elements are found usually brought the new element to light, and in this way one blank space after another was filled. To-day ninety-six elements are known. Ninety-two of them occur naturally, and the others are a result of splitting the atom.

The number of electrons in the outer shell is the thing which determines the character of an element. Just tell a chemist something about the electron structure, and you need tell him nothing more about the element. He knows just where it belongs.

CHEMISTRY

Reading Unit No. 3

SOME STRANGE DEEDS AMONG THE ATOMS

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

What is table salt? 1–551
The chemist's shorthand, 1–551-52
Mixtures and compounds, 1–552-53
The Law of Definite Proportions, 1–553, 555
Atomic weight, 1–553-55
What happens to coal when it burns? 1–555-57
Ions, 1–557-58
Solutions, 1–557

Things to Think About

How do elements combine?
Why do we get two gases from coal?
How is the weight of the atoms in a compound determined?
Why do the molecules of salt break up when put into water?

Picture Hunt

What is the purpose of a hospital's chemical laboratory? 1–550
How does the draft of a furnace determine the gases given off by a fire? 1–556

Related Material

How is chromium used in tanning leather? 9–68
How is hydrogen used in balloons and airships? 1–473, 10–314, 316
Why was magnesium important in World War II? 9–422
What chemicals are found in precious stones? 9–428
How is iron smelted? 9–398
How is silver smelted? 9–388
How is coal mined? 9–435
What is the source of radium? 9–424

Leisure-time Activities

PROJECT NO. 1: Make some iron sulphide, 1–552-53.
PROJECT NO. 2: Show that water containing dissolved salts carries electric current, 1–557.

Summary Statement

Elements combine to form compounds according to definite laws. The properties of compounds are different from the properties of the elements which they contain.

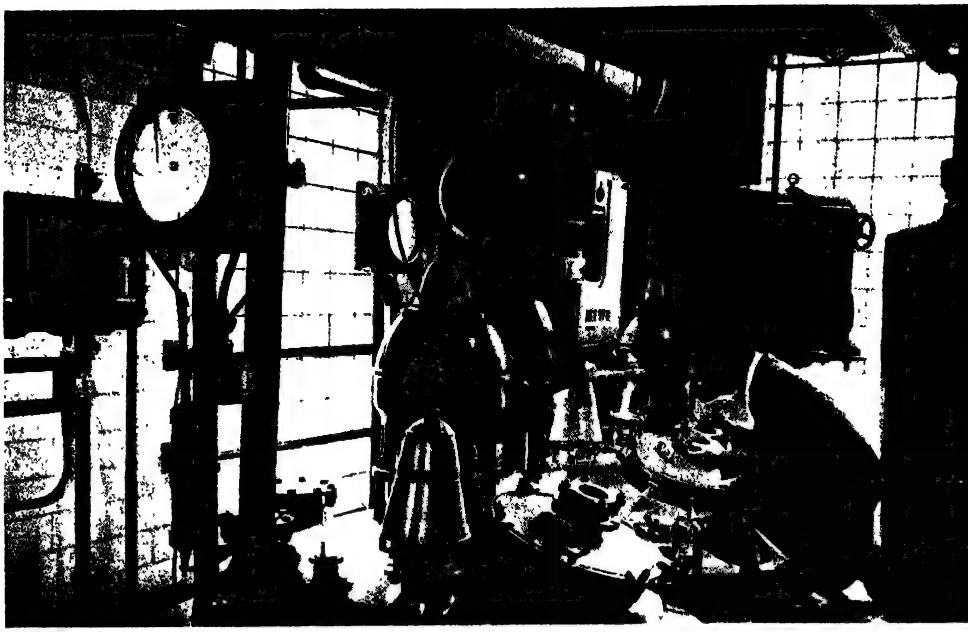


Photo by E. R. Squibb & Sons

Because our bodies are complicated little chemical laboratories the chemical laboratory of a hospital or of a large drug company is very important. For it is there that the chemistry of our bodies is studied and cures are found. Above, you may see machinery used in making sulfa drugs, those remarkable chemical compounds that have conquered certain of our worst germs and can cure some of our deadliest diseases.

SOME STRANGE DEEDS *among the* ATOMS

How Liquid Water Is Made from Two Invisible Gases, and Common Salt from Two Poisons

IT MAY sound old-fashioned to say that a thing may be regarded as the sum of all its parts. A triangle is made with three straight lines, and a square with four. You may, then, look upon a triangle as the assemblage of three lines, and as possessing nothing that the three lines do not give it.

Well, it *is* old-fashioned to make such a statement, for more and more we come to see that a thing taken as a whole may have characteristics which do not reside in its parts. A triangle brings ideas to our minds which would never be aroused by three straight lines in any other arrangement. We may think of drawing sets, with their triangles, of certain emblems of lodges, of our last teacher of trigonometry, or of a hundred other things. We surely think of any person as more than two arms, two legs, a head, and a few other members. He is not just the sum of his parts, for he can lose an arm or a leg and still be the same person. And then there is the problem of the mob; many times you have heard that a large number of people will be more cruel or more daring than any of the individuals in it. The mob is something more than the sum of all the persons in it.

The chemist is never surprised or shocked by such ideas, for every day he sees that the things he puts together give him results which never could have been guessed from the original materials. He knows that water is made of two invisible gases, and that common salt is the result of a still stranger

Element	Symbol	Atomic Number	Average Atomic Weight	Element	Symbol	Atomic Number	Average Atomic Weight
Actinium	Ac	89	226.	Molybdenum	Mo	42	96.0
Aluminum	Al	13	26.97	Neodymium	Nd	60	144.27
Americium	Am	95		Neon	Ne	10	20.2
Antimony	Sb	51	121.77	Neptunium	Np	93	237.
Argon	A	18	39.91	Nickel	Ni	28	58.69
Arsenic	As	33	74.96	Niobium	Nb	41	93.1
Astatine	At	85	211.	Nitrogen	N	7	14.008
Barium	Ba	56	137.37	Osmium	Os	76	190.8
Berkelium	Bk	97		Oxygen	O	8	16.000
Beryllium	Be	4	9.02	Palladium	Pd	46	106.7
Bismuth	Bi	83	209.00	Phosphorus	P	15	31.027
Boron	B	5	10.82	Platinum	Pt	78	195.23
Bromine	Br	35	79.916	Plutonium	Pu	94	238.
Cadmium	Cd	48	112.41	Polonium	Po	84	210.
Calcium	Ca	20	40.07	Potassium	K	19	39.096
Californium	Cf	98		Praseodymium	Pr	59	140.92
Carbon	C	6	12.000	Promethium	Pm	61	147.
Cerium	Ce	58	140.25	Protactinium	Pa	91	234.
Cesium	Cs	55	132.81	Radium	Ra	88	225.95
Chlorine	Cl	17	35.457	Radon	Rn	86	222.
Chromium	Cr	24	52.01	Rhenium	Re	75	187.
Cobalt	Co	27	58.94	Rhodium	Rh	45	102.91
Copper	Cu	29	63.57	Rubidium	Rb	37	85.44
Curium	Cm	96		Ruthenium	Ru	44	101.7
Dysprosium	Dy	66	162.52	Samarium	Sm	62	150.43
Erbium	Er	68	167.7	Scandium	Sc	21	45.10
Europium	Eu	63	152.0	Selenium	Se	34	79.2
Fluorine	F	9	19.00	Silicon	Si	14	28.06
Francium	Fr	87		Silver	Ag	47	107.880
Gadolinium	Gd	64	157.26	Sodium	Na	11	22.997
Gallium	Ga	31	69.72	Strontium	Sr	38	87.63
Germanium	Ge	32	72.60	Sulphur	S	16	32.064
Gold	Au	79	197.2	Tantalum	Ta	73	181.5
Hafnium	Hf	72	178.6	Technetium	Tc	43	99.
Helium	He	2	4.00	Tellurium	Te	52	127.5
Holmium	Ho	67	163.4	Terbium	Tb	65	159.2
Hydrogen	H	1	1.008	Thallium	Tl	81	204.39
Indium	In	49	114.8	Thorium	Th	90	232.15
Iodine	I	53	126.932	Thulium	Tm	69	169.4
Iridium	Ir	77	193.1	Tin	Sn	50	118.70
Iron	Fe	26	55.84	Titanium	Ti	22	48.1
Krypton	Kr	36	82.9	Uranium	U	92	238.17
Lanthanum	La	57	138.90	Vanadium	V	23	50.96
Lead	Pb	82	207.20	Wolfram	W	74	184.
Lithium	Li	3	6.940	Xenon	Xe	54	130.2
Lutetium	Lu	71	175.0	Ytterbium	Yb	70	173.6
Magnesium	Mg	12	24.32	Yttrium	Y	39	88.9
Manganese	Mn	25	54.93	Zinc	Zn	30	65.38
Mercury	Hg	80	200.61	Zirconium	Zr	40	91.

union. One element is sodium (sō'dĭ ŭm), light in color and weight, and so active chemically that a piece of it, if swallowed, would scorch our throats badly. This metal combines with a greenish, heavy, poisonous gas called chlorine (klō'rĭn) to make ordinary table salt!

Though he often does not know what the product is going to look like, the chemist is not altogether ignorant of what will happen when elements combine. He knows one very handy rule: that the weight of the compound is always equal to the weight of the elements which go into it. The weight never changes, whatever else may happen, and in weighing things the chemist finds out still more about how elements make compounds.

The chemist cannot take the time and space to write out such facts as these: two atoms of hydrogen (hī'drô-jĕn) combine with one atom of oxygen to form one molecule (mŏl'ē-kūl) of water, or one atom of sodium combines with one atom of chlorine to form one molecule of sodium chloride, commonly called salt. The chemist has found a much shorter way. First, each element is known by one or two letters from its modern or its older name, usually its Latin name. Thus H stands for hydrogen, O for oxygen, C for carbon, He for helium, and Pb for lead. Each of these signs stands

Photo by Keystone View Co.

Above is one of Uncle Sam's chemists testing foods for purity. Everyone knows how important it is to make sure that home products and foods from foreign countries are absolutely safe.

not only for the element, but for one atom of the element, so that H means to the chemist one atom of hydrogen and O one atom of oxygen. But what is his sign for two atoms, or three atoms? A little number at the lower right side tells the number of atoms he means. Thus H_2, He_3, and C_4 mean two atoms of hydrogen, three atoms of helium, and four atoms of carbon. To tell what happens when two elements combine, the chemist uses a formula like this: $H_2+O=H_2O$; which means that two atoms of hydrogen and one atom of oxygen make one molecule of H_2O, or water. Notice the "equal" sign. It means the same thing as in arithmetic—that there must be equal quantities on each side of it. If you add up the number of atoms of an element on one side, it must be the same on the other side, since none of that element disappears during the combination. Moreover, the "equal" sign tells us that we can multiply or divide both sides by the same quantity without changing the truth of the formula. If we wanted to get two molecules of water instead of one, we could write

$$2H_2 + 2O = 2H_2O;$$

for the two in front refers to everything that follows just after it, so that $2H_2O$ means 2 times H_2O.

We can make an experiment to illustrate the expression $Fe + S = FeS$; that is, that one atom of iron unites with one atom of sulphur to form one molecule of "iron sulphide." Sulphur we can get at the druggist's, in the form of "flowers of sulphur"; half an ounce is enough. Iron filings, or iron in small bits, is to be had at the hard ware store. If we take these two, about half an ounce of sulphur and an ounce of iron, and merely mix them together, we can then separate them again in several ways. A magnet will draw the iron particles out of the mixture, leaving the sulphur behind. A liquid known as carbon disulphide will dissolve the sulphur without touching the iron. Or if we merely look at the mixture we can see that the iron is still there as little bits of iron; nothing at all has happened to it. The sulphur, too, is the same fine yellow powder. For as yet we have made nothing but a "mixture" of our two elements.

How Compounds and Mixtures Differ

But now if we can get a "test tube" such as chemists use, we can show very plainly how a chemical compound differs from a mere mixture. We put the mixture, in the tube, over a very hot fire. At first, some of the sulphur will start burning, and unless

we are using a rather narrow tube, we are likely to be partly choked by a rather biting, ill-smelling gas. It should not be breathed for long, and never deeply. What we are now doing is making the sulphur combine with the oxygen of the air; that is what happens to anything when it burns—it combines with the oxygen of the air. In the case of the sulphur, the chemist would express it as follows:

$$S + O_2 = SO_2$$

That is to say, one atom of sulphur combines with two atoms of oxygen to form one molecule of "sulphur dioxide." Sulphur dioxide, the ill-smelling gas, is used widely for bleaching straw hats, flour, and other things.

Making Iron Sulphide

After being heated a while longer the whole mass starts to glow, and no more gas is given off. Even if we remove our container from the fire, its contents now continue to glow. The glowing shows that the process $Fe + S = FeS$ is going on.

When the whole thing has cooled—we should put it under water to be sure—and we remove what is left in the tube, we shall have a number of surprises. First, the entire contents may now be taken out in one piece; there are no signs of the powders put in at the beginning. Second, the lump we hold in our hand looks like neither iron nor sulphur. It looks more like a cinder such as one may see along a railroad track. What is more, it has none of the properties of either of the two elements that went into its making. It is not attracted by the magnet, and no part of it can be dissolved in carbon disulphide. It is a new thing—a chemical compound, and very different from the simple mixture with which we started.

The Definite Proportions in a Compound

If we do this experiment very carefully and examine the iron sulphide by grinding it up and looking at it with a microscope, or testing it with a strong magnet, then we may find that there are some little particles of iron still left in the compound. Some of the iron has been left over. Or, even during and after the glowing, we may get the choking smell of sulphur dioxide, showing that some sulphur is still left over to combine with the oxygen of the air after all the iron is gone. But never do we have both iron and sulphur left over.

Now suppose we tried a great many times to get just the right quantity of each element, so that not a bit of either would be left over—so that there would be nothing left but iron sulphide. We should find that we needed exactly 7 parts by weight of iron to 4 parts by weight of sulphur in order to get this result. So 7 grams of iron combine with 4 of sulphur, 14 with 8, 28 with 16, 56 with 32, and so on, as far up as you like—the iron in the compound always being greater by weight than the sulphur, in the proportion of 7 to 4. So we are dealing with a perfectly definite thing.

In the mere mixture we could put any amounts of sulphur powder and iron filings together, and no matter what the proportions, we should still have a mixture of iron and sulphur. Now, however, if we take more than a certain proportion of iron, some of it is sure to be left over from the compound, and if we take too much sulphur, it cannot all be used up in combining with the iron.

The Weight of Atoms in a Compound

Now let us imagine that we want to divide into little pieces the compound we have made. No matter how little we may make the pieces, there will always be 7 parts of iron to 4 parts of sulphur in them. Let us say that we have a handful at first. Then we cut it in half, and then half of the original piece into two quarters. One of the quarters we continue dividing—into eights, sixteenths, thirty-seconds, and on and on and on. After a while we get down to a piece so small that it has only a few molecules in it. And after dividing it several times more, we arrive at the smallest possible piece of iron sulphide—one molecule. We cannot divide it any further, for if we did we should no longer have iron sulphide, but the two atoms iron and sulphur.

In this molecule of iron sulphide, the proportion of iron to sulphur, by weight, is 7 to 4. But since we have only one atom of each, the atom of iron must be heavier than the sulphur atom in the proportion of 7 to 4.

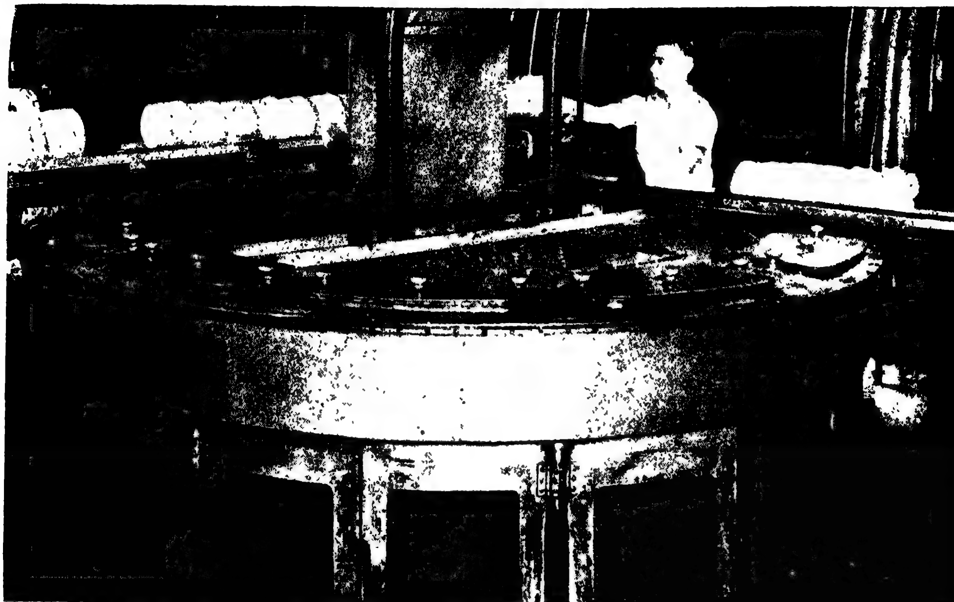


Photo by Du Pont

We must thank the science of chemistry for a great many of the things we use every day. We should not be able to have many of our most useful fabrics were it not for our chemical knowledge. The white cakes on the moving belt above are rayon in the process of drying before becoming stockings or dress goods.

So now we understand why we cannot use more than a certain quantity of iron to ombine with a fixed amount of sulphur: each atom of sulphur joins with one atom of iron, and if there are too many atoms of iron, the extra ones will simply have to do without a mate; they will be left over as pure iron. Or if we use too much sulphur, some of that will be left over. And more than that, when two elements such as these combine atom for atom, the proportions by weight in which they combine give us the proportion by which one atom is heavier than the other, just as we found the iron atom is as 7 to the sulphur atom's 4.

The Weights of Sulphur and Oxygen

Atomic (ȧ-tŏm′ĭk) weights are measured in "atomic mass units"—abbreviated a.m.u., and the oxygen atom has been chosen as standard, with a weight of 16 a.m.u. It might have been another number, but scientists have agreed on sixteen. Then they set about to see how much lighter or heavier all the other atoms are. They found out in just the way we did for iron and sulphur. We saw in our little experiment that at one time we got this process:

$$S+O_2=SO_2$$

We have put the atomic weight of oxygen at 16, and we find out, by weighing, the quantities of sulphur and oxygen which combine. It turns out that the sulphur, with one atom, weighs 32, and the oxygen, with two atoms, also weighs 32. One atom of sulphur therefore weighs twice as much as one atom of oxygen. So if oxygen weighs 16, sulphur weighs 32.

Finding the Atomic Weight of Iron

Now knowing the atomic weight of sulphur to be 32, we can find the atomic weight of iron. From our experiment we found that the iron atom is heavier than the sulphur atom in the proportion of 7 to 4. So we have this simple little problem to solve: 7 is to 4 as what number is to 32? The answer is 56; and that is the atomic weight of iron. Knowing the atomic weight of iron, we can next measure the amount of some other element which combines with it and find out

the atomic weight of that other element—and so on until we have found out the relative heaviness of all the ninety-two elements.

Elements of high atomic weight should be heavy, since an element is nothing but a large number of atoms, and if the atoms are heavy, so is the element. We may expect lead, mercury, and gold to be elements of high atomic weight, and they are. Hydrogen is the element of lowest atomic weight, the lightest element known. Its atomic weight is 1. Helium, carbon, and nitrogen are among the other seven elements which are lighter than oxygen. The element of heaviest atomic weight is curium, a man-made element. It is approximately 15 times as heavy as oxygen.

What a distance the simple experiment with iron and sulphur has taken us! We had better stop to "take stock." How many things did that experiment illustrate?

The Law of Definite Proportions

We learned first that a mixture is very different from a chemical compound in that you can use any proportion of the elements in a mixture. You can mix a pound of sulphur with a ton of iron filings if you so desire.

Next, after heating the iron and sulphur, we found that the resulting substance in no way resembled either iron or sulphur. That this is not unusual we know from the case of water, which is made of two invisible gases. Chemical compounds in general do not resemble the elements of which they are made.

Then we did some experiments in weighing the amounts of sulphur and iron, and found, to begin with, that the "equal" sign in the chemists' way of describing things really means "equal." The numbers of atoms on the two sides of the sign must be equal, and so must the weights. That is, the weight of the compound in $Fe + S = FeS$ is equal to the sum of the weights of the elements making it. Furthermore, iron and sulphur will not combine in all proportions. We must take a definite quantity of one to combine with a definite quantity of the other. If we take too much of one we shall surely have some of it left over. This rule the chemist calls "The Law of Definite Proportions." Definite proportions are a sure sign of chemical compounds; any other proportions are a sign of a mixture.

The Proportions in Which Elements Combine

We found the reason for the definite proportions in which elements combine. It is simply that they combine atom for atom, or in some such simple relationship. When all the atoms of an element are used up in combining with the atoms of another, and there are still some atoms of that other element, then these extra ones cannot find anything with which to join, and they remain as the element. If all the atoms of sulphur are used up and there are still more iron atoms present, these iron atoms cannot do anything but remain iron; and we find little particles of iron in the iron sulphide.

Finally, by weighing things, we found that some atoms are heavier than others. Iron is to sulphur as 7 is to 4. That is, if we have two equal boxes, one full of iron and the other full of sulphur, the box of iron will be almost twice as heavy as the other. If we call the oxygen atom 16, we can find out which atoms are heavier, and which ones lighter than this one. The elements of high atomic weight are the heavy ones, such as lead and gold. The ones of low atomic weight are the light ones, such as hydrogen and nitrogen.

Those of us who use hard coal or coke as fuel in our furnaces can learn a lesson in chemistry while stoking the fire.

First, we may notice that when coal is put into the furnace and the bottom draft is opened to allow the fire to pick up, a brisk yellow blaze plays above the coals. Sparks leap upward and vanish. Indeed, probably a large part of the blaze is made of such sparks, which are themselves glowing particles of coal.

What Causes the Blue Blaze from Coal?

After the fire has a good start, it is customary to close the bottom draft and to open the furnace door. In this way the fire is kept from burning too fast In a little while if we look into the door we can see a blue blaze, not burning steadily in any one place, but

disappearing and then reappearing with a gentle pop or puff. There is no yellow flame now, and the draft is not strong enough to bear sparks upward. What is the explanation of these simple facts?

When carbon, or coal, burns in a good draft, the following action takes place:

$$C + O_2 = CO_2$$

That is, one atom of carbon unites with two atoms of oxygen from the air to form one molecule of a gas known as "carbon dioxide." Carbon dioxide is familiar as the gas in ginger ale and soda water. It is not inflammable, has no smell, and is harmless under most circumstances. It passes up the chimney and is lost in the air.

When the bottom draft is closed, very little air comes up through the layer of coals. The only draft is caused by leaks. Under these conditions, we might imagine the coal saying to itself: "I must have oxygen in order to burn, but the draft is closed so tightly that only a very small amount is passing up through my glowing embers. But I can economize; instead of taking two atoms of oxygen for each atom of carbon, I shall take only one." And that is what the coal does, for the process is

$$C + O = CO$$

Since oxygen atoms always travel in pairs, there are two oxygen atoms to a molecule; so the chemist would rather write this

$$2C + O_2 = 2CO$$

The meaning is just the same. With the draft closed, then, we have one atom of carbon uniting with one atom of oxygen to form one molecule of "carbon monoxide," or CO. Carbon monoxide is a gas without smell or taste, invisible, quite poisonous, and especially dangerous because its presence is not noticed. It would be foolhardy then, to close the draft on our furnaces but for the fact that carbon monoxide is inflammable. It burns, and with a blue flame! So the blue flame you see can be explained in this way:

$$2CO + O_2 = 2CO_2$$

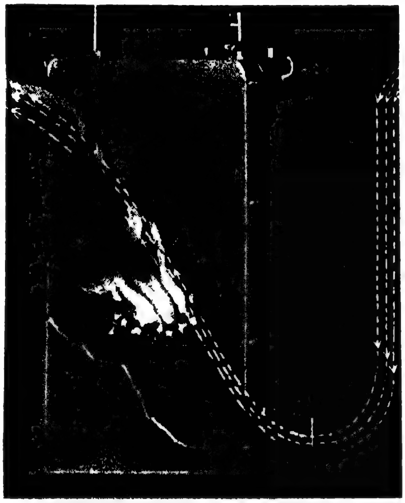
On top of the coals the carbon monoxide burns to the harmless carbon dioxide, giving us, in the process, a lovely, flickering blue flame. It burns on top of the coals only, because plenty of oxygen from the open door can reach it there. So in the lower layers of coal we have one chemical process going on—

$$2C + O_2 = 2CO$$

and in and above the upper layers

$$2CO + O_2 = 2CO_2$$

The flame flickers because after burning for a moment all the CO is gone from that one spot, and the flame goes out. Then the slight draft coming upward brings some more CO, and when the open air is reached the blue flame once more comes into being.



This picture shows you a coal furnace with its lower draft open. The fire is burning briskly. There is plenty of oxygen; so each atom of carbon is combining with two atoms of oxygen—which are all it can hold. If you shut the draft, there will not be so much oxygen; then each atom of carbon must be content with one atom of oxygen instead of two.

Something new to us, however, is happening in the furnace. Never before have we seen two elements combining in more than one way. Iron and sulphur form FeS, and we may have thought that this was all the two elements could do together. But they can unite to form FeS_2 and even other compounds, just as carbon in the furnace forms both CO and CO_2. If we learn why carbon acts in this way, we shall understand why iron and other elements have a "choice" when they form compounds with another element.

Our little table which you will find in another chapter shows you that carbon has two shells of electrons, the usual inner one of two, and an incomplete outer one of

four. When it combines with oxygen it loses electrons from this outer shell. The secret is, however, that the carbon atom does not have to lose all four. It may lose only two, or it may lose all four. If it loses two, one atom of oxygen, which needs two electrons to add to its six in the outer shell, will take these two; and the one atom of carbon and one atom of oxygen will combine to form one molecule of carbon monoxide (CO). But if the carbon atom loses all four electrons, it will take two oxygen atoms to capture these four, since each oxygen atom can take only two. And now one carbon atom combines with two oxygen atoms to form carbon dioxide (CO_2).

Why We Get Two Gases from Coal

We may say that the oxygen atoms are trying to take away electrons from the carbon atoms. If there are a great many oxygen atoms they have a very strong pull, and succeed in capturing all four of the electrons which carbon can lose. But if there are only as many oxygen atoms as carbon atoms, then the pull is not so strong and carbon yields up only two of its electrons. And that is why it may combine in these two ways.

Now we have not violated our "law of definite proportions," which said that when two elements combine they always do so in definite ratios. All that the furnace has taught us is that there is more than one definite proportion. Thus we have seen the proportions of iron and sulphur in FeS to be 7 to 4. In FeS_2 the proportions are just as definite; they are always 7 to 8, and you can easily see why, for there is just twice as much sulphur in a molecule of this compound. In CO the proportions by weight are 3 to 4, and in CO_2 they are 3 to 8, because there is twice as much oxygen in the second compound. So even if two elements do combine in a number of ways, each compound has perfectly definite proportions of each element by weight.

The Action of Salt in Water

When a bit of common salt is put into water, a series of very remarkable changes can be noted. You may say that the disappearance of the salt is itself a wonderful thing, at least if you have ever wondered why the salt vanishes. Yet although it is gone from sight, we can still taste it.

The chemist uses the same word that we use for this action of salt. He says it "dissolves" in water. The product he calls a "solution," in this case a solution of salt in water. We may have solutions of sugar in water, sugar in alchol, baking powder in water, and a great many other kinds. In a large number of cases, however, the same sort of action takes place, so that we may speak of all of them together.

Take a glass of pure water and put into it the two wires from a storage battery, keeping the wires apart. Nothing happens. Now while the wires are still in the water, put in a pinch of salt. Immediately bubbles begin to collect on one wire, detach themselves, and rise to the surface. If you collect the gas by putting a glass, filled with water, upside down over the wire, you will find that you have collected hydrogen, the lightest thing in the world. After a few minutes, you will also see that the other copper wire is losing its bright shiny appearance. Evidently some mysterious things are going on in the solution through which an electric current is passing, and the salt must be responsible for them. So let us go back to this very familiar compound.

What Are "Ions"?

Salt is made of sodium and chlorine, combined atom for atom ($NaCl$). We have already seen that sodium is very eager to lose one electron, and that chlorine is just as eager to gain one. Sodium, through the loss, gets a positive charge, and chlorine, through the gain, gets a negative one. When these two are close together, as they are in a molecule of salt, the result is no charge at all: the one positive charge simply neutralizes the negative one.

When we put salt into water, however, all of this is changed. The sodium is freed from the chlorine and each can wander around in the solution. These particles in the solution, then, are really sodium atoms minus one electron—which is the same thing as saying that they have a positive charge. The chem-

ist gives these charged particles a separate name. He calls them sodium "ions," a name that comes from the Greek word "to go." In the same way, the negatively charged particles are not really chlorine atoms, but are chlorine ions. And now let us see why the name of these charged particles means "things that go."

Remember that unlike charges attract. One wire from the battery is positive (+), and the other negative (−). So all the negatively charged particles are attracted to the + wire and all the positively charged ones to the − wire. The sodium ions, with their positive charges, stream toward the negative wire, and the chlorine ions toward the positive wire. Something happens to each one at its destination.

When a sodium ion arrives at the wire, its positive charge is neutralized by the negative charge in the wire, and the sodium ion becomes a sodium atom! Now do you remember what happens to ordinary sodium when it is placed in water? It is so eager to lose an electron that it combines with the water, and this is how it does it:

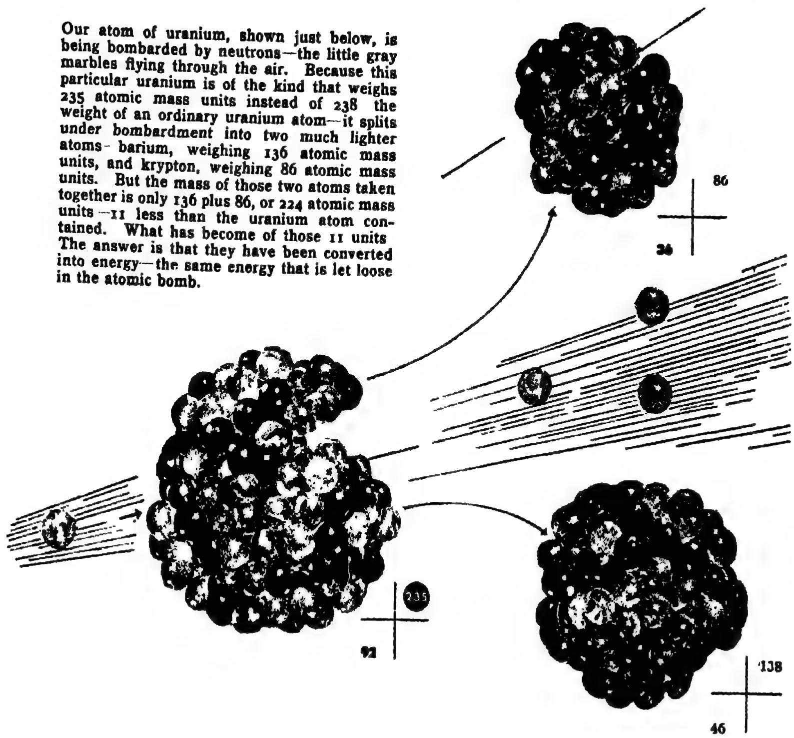
$$2Na + H_2O = 2NaOH + H_2$$

That is, two atoms of sodium combine with one molecule of water to form two molecules of "sodium hydroxide"—caustic soda—and one molecule of hydrogen. So right around the negative wire we have caustic soda and hydrogen formed. The caustic soda is dissolved in the water and remains there. The hydrogen is not dissolved, but appears as bubbles on the wire, finally escaping into the air.

At the other wire, chlorine ions gather and become chlorine atoms on touching the wire. Chlorine atoms, you remember, are trying to find one more electron; there are seven in the outer shell, and chlorine is, for this reason, very active. So it "attacks" or combines with, the copper in the wire, and the tarnish you see is a "chloride of copper." If, instead of putting the positive wire into the solution, we had attached it to a piece of carbon, and put the carbon in, we should have obtained the poisonous gas chlorine. Since it does not attack carbon, it would appear as bubbles, and we could collect it as a greenish, ill-smelling gas.

So we have to tell a long story to explain just why there are bubbles on one wire and tarnish on the other. But in telling that story we have learned quite a few things about "solutions." Many chemical compounds act in just the same way as does salt—they dissolve and split into positive and negative ions. We should never suspect the presence of these charged particles, because when they are separated they are much too small to see. But when we pass a current through a solution containing them, strange things happen. Common salt gave us a rather complicated series of events, and other compounds will give still other results.

If a pinch of salt will produce all the actions we have just described, need we ever again wonder at the great difficulty of explaining apparently simple things? Almost any question you may ask, if followed even a little way, becomes so difficult that the greatest minds of the age cannot answer it How does a tree grow? What is in the stars? Are any other planets inhabited? Why does candy taste sweet? All these are questions much like the one we asked as to what happens to a pinch of salt when you put it into water. Even that question we have answered only in part; for the entire answer would require more than all the knowledge in the universe.



Our atom of uranium, shown just below, is being bombarded by neutrons—the little gray marbles flying through the air. Because this particular uranium is of the kind that weighs 235 atomic mass units instead of 238 the weight of an ordinary uranium atom—it splits under bombardment into two much lighter atoms—barium, weighing 136 atomic mass units, and krypton, weighing 86 atomic mass units. But the mass of those two atoms taken together is only 136 plus 86, or 224 atomic mass units—11 less than the uranium atom contained. What has become of those 11 units The answer is that they have been converted into energy—the same energy that is let loose in the atomic bomb.

THE ENERGY LOCKED IN THE ATOM

How Man Learned to Change Solid Matter into Vast Amounts of Energy and Ushered In a New Era for the Human Race

IT WAS half past five of a stormy morning on July 16, 1945. In pouring rain shot through with flashes of lightning a tense little group of distinguished scientists and military men had gathered in the heart of the lonely New Mexico desert to watch one of the most momentous experiments of all time. Two billion dollars had been spent by our government in order that this event might come to pass, and hundreds of thousands more had been spent by universities and other foundations of learning in discovering facts that had to be known before the experiment could be attempted.

Now, in a distant part of the Alamogordo (ä′lȧ-mō-gôr′dō) Air Base, 120 miles southeast of Albuquerque, a gigantic bomb had been mounted on a high steel tower built for the purpose. At a signal the bomb was set off, and with its earth-shattering explosion, which melted the tower with its heat, mankind strode ahead a thousand years in time and entered a new age—the Age of Atomic Energy, in prospect more dazzling and at the same time more forbidding than any of the ages through which man has come.

No one had known whether the bomb would explode or not. Its inventors could only hope—hope that their creation would have the destructive power to bring Japan to her knees and that mankind would have a new source of energy powerful beyond our

wildest dreams. The success of the experiment was greater than anyone had dared hope for. A small amount of matter, produced in especially constructed industrial plants, was made to release the energy locked up in its atoms since the beginning of time. No longer is man entirely dependent on the sun as the final source of all his power. For the first time vast amounts of energy are his for the asking.

The Gravest Problem of Mankind

What is man going to do with this new source of power? How can he best use it? Can we control it for the good of mankind or is it going to destroy the human race? The answer rests with man himself—with you and me and the people who live next door. We may enjoy a future more beautiful than our wildest dreams if men will be honest and kindly and play the game fairly. But if they keep on being brutal and dishonest and greedy the nations will continue to look at each other with fear and suspicion, and some day the atomic bombs will begin to fly through the air and civilization will be wiped out. It is for man himself to decide. No one else can decide for him.

Now if we are to act wisely and would make a lasting resolution to do so, we must understand just what atomic energy is and why it is so deadly. So if you will put on your thinking cap and read carefully and slowly, we shall lead you along the road that scientists have cleared with such difficulty and to which they have devoted so many years of toil and self-denial. For the achievement belongs to no one man and no one nation. It is the work of an army of men toiling in laboratories in every civilized country on the face of the globe.

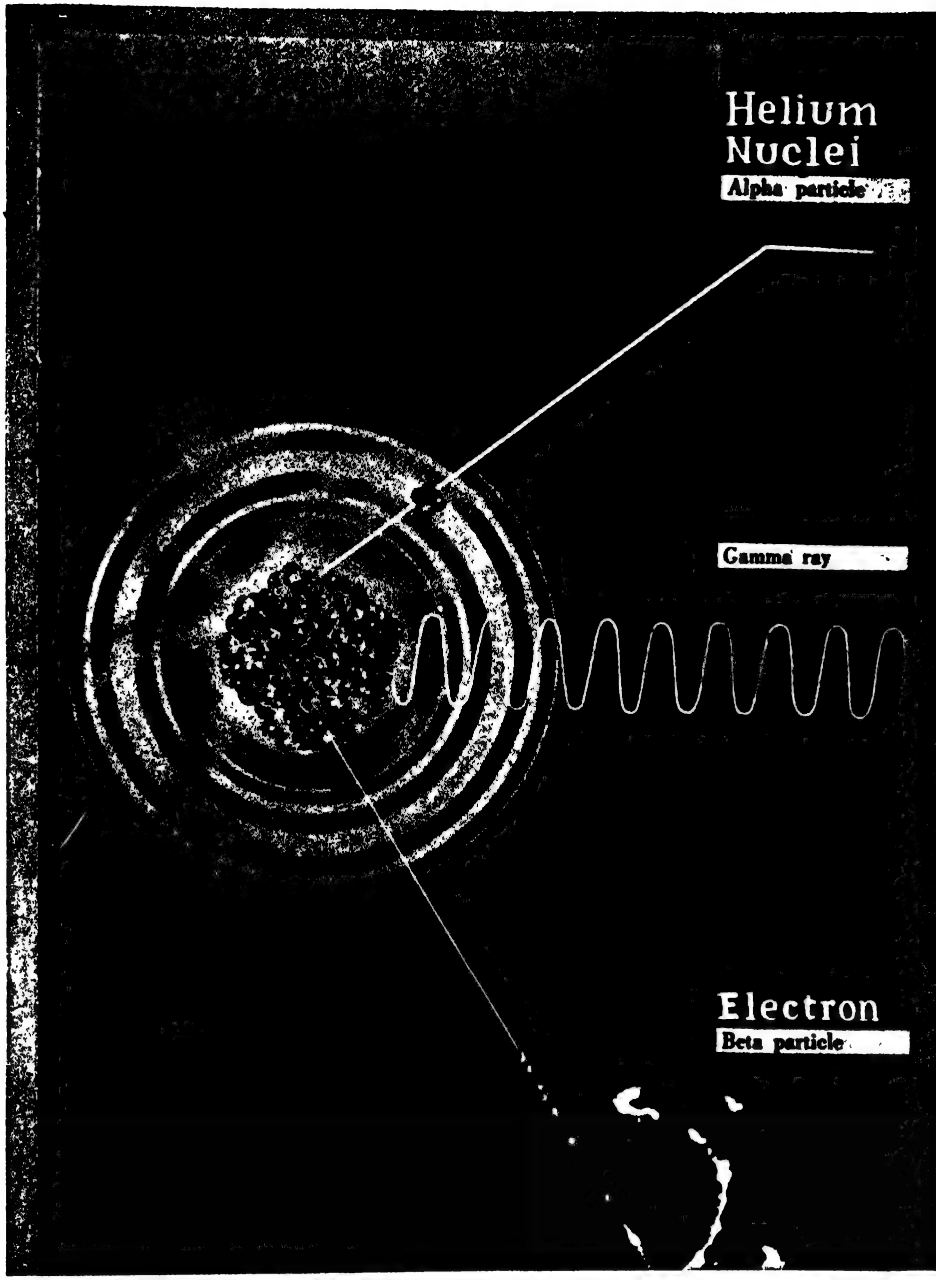
Let us begin our study of atomic (ă-tŏm'-ĭk) energy by making a short summary of what we already know about atoms from earlier chapters in this book. As you read each statement in this summary, be sure you understand exactly what it means. If you are hazy about any of it, go back to the earlier chapters and clear the matter up.

Do You Understand What Follows?

1. There are 92 substances found in nature. Alone or in combination with one another they make up everything in the physical universe.
2. These 92 simple substances are called "elements."
3. The smallest particle of an element is an atom.
4. Atoms contain, among other things, positive bits of electricity called protons (prō'tŏn) and negative bits of electricity called electrons (ē-lĕk'trŏn).
5. The protons are contained in the nucleus of the atom, while the electrons revolve about the nucleus, much as the planets revolve about the sun.
6. The number of protons in the nucleus of an atom of any given substance is always the same as the number of electrons circling about in the outer shell of the atom.
7. The atomic number of an element is always the same as the number of electrons which revolve about the nucleus in an atom of the substance.
8. The atoms of different elements have different weights.
9. The atomic weight of an element is expressed in what are called "atomic mass units"—abbreviated "a.m.u."—and is based on the atomic weight of oxygen. Scientists have agreed that an oxygen atom weighs 16 atomic mass units.
10. The greater the atomic number, the greater is the atomic weight of an element.

What Is a Neutron?

All of the above is part of a scientific theory known as the atomic theory. On the basis of these ideas we have come to understand much of what goes on in the universe. There are, however, gaps in the theory—questions yet to be answered. Not long ago one of the most puzzling of these questions was answered and an important gap in our knowledge was filled in. The problem was this: An atom of hydrogen (hī'drō-jĕn) contains one proton and one electron. An atom of helium (hē'lĭ-ŭm) contains two protons and two electrons. Since the atomic weight of hydrogen is taken to be 1, the atomic weight of helium should be 2. Yet careful measurement shows that the helium atom weighs 4 atomic mass units. How can it be?



It was the discovery of radium in 1896 which started scientists on the road to the splitting ot the atom. They had thought that the 92 elements were eternally fixed, and that one of them could never be changed into another. But radium—with 88 protons and 138 neutrons in its atom--proved to be constantly shooting particles out into space and thus breaking down into lead. As you see above, a radium atom sends out three kinds of radiations: 1) the alpha particle, which is really a helium nucleus containing two protons and two neutrons that break off as a unit and go rushing away at a speed of 33 million miles an hour, 2) the beta particle, which is an electron ejected when the radium is approaching its end, and 3) gamma rays, which are pure energy radiations sent out as the radium breaks down.

The scientists dug more deeply into the problem. By clever methods they succeeded in weighing electrons and protons. They found that the weight of the electron was so small in comparison with the weight of the proton that it could be disregarded entirely. But they also found that for all intents and purposes the proton weighed 1 atomic mass unit. This made the problem of the weight of the helium atom even more complex. The solution came late in 1932 when J. Chadwick, an English scientist, announced that he had discovered a new particle which he had succeeded in ripping out of the heart of atoms. The new particle was studied with great interest. It was generally agreed that it was nothing more than a proton and electron in very, very close association. Since the charges on the proton and electron canceled each other completely, the particle was electrically neutral. So it was decided to call the new particle a "neutron" (nū′trŏn).

Neutrons are found in the nuclei (nū′klē-ī)—the plural of "nucleus"—of all atoms except ordinary hydrogen. Since the proton weighs 1 atomic mass unit and the weight of the electron is too small to be taken into account, the neutron may be said to weigh 1 atomic mass unit. In this way Chadwick's discovery solved the problem of the weight of the helium atom. If we assume that the helium atom contains a nucleus of 2 protons and 2 neutrons and has 2 electrons revolving about the nucleus, we have an atom with an atomic number of 2, because of the 2 electrons in the outer shell, and an atomic weight of 4. This means that there are 2 atomic mass units for the 2 protons plus 2 atomic mass units for the 2 neutrons.

An Easy Shorthand

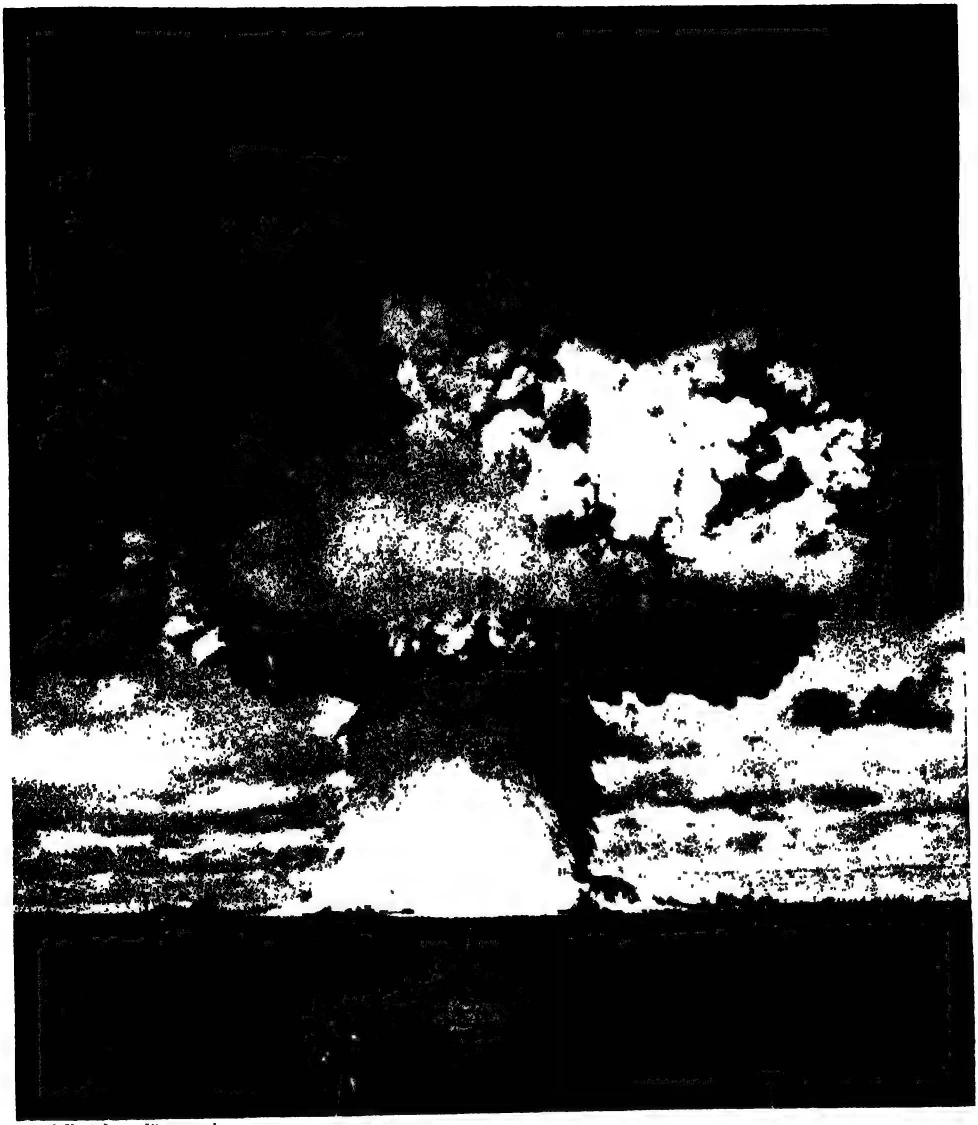
Scientists have adopted a kind of shorthand for expressing the atomic number and the atomic weight of an element. They write the atomic number below and in front of the chemical symbol, and the atomic weight above and after the symbol. For example, the symbol for helium is "He". Its atomic number is 2, and its atomic weight is 4. So in writing, it is described thus: ${}_2He^4$. Uranium (ū-rā′nĭ-ŭm)—atomic number 92, atomic weight 238—is written as ${}_{92}U^{238}$.

As scientists now believe, atoms contain at least three different kinds of particles—protons, neutrons, and electrons. In general, an atomic number indicates the number of electrons in the outer shell. To be electrically neutral, a nucleus must contain an equal number of protons and electrons. Neutrons make up the remaining mass of—that is, material in—the atom. The atomic weight indicates the total number of protons and neutrons in a nucleus. For example, the atom ${}_{92}U^{238}$ is composed of 92 electrons—circling about in the outer shell—and a nucleus of 92 protons and 146 neutrons—$92 + 146 = 238$.

What Is "Heavy Water"?

It was Dr. Harold Urey (ū′rĭ) who provided another missing link in the chain of atomic theory, and for this distinguished work was awarded the Nobel Prize in Chemistry in 1934. Before his discovery several investigators had noted that samples of hydrogen differed from one another in atomic weight. Dr. Urey reasoned that there might be more than one kind of hydrogen, and that one kind might weigh more than another. If, for example, there were two kinds, the difference in atomic weight of various samples could be easily accounted for, inasmuch as any one sample might differ from other samples in the proportions of the two kinds of hydrogen that it contained.

Developing this idea, Dr. Urey discovered "heavy hydrogen"—hydrogen with an atomic number of 1, like ordinary hydrogen, but with an atomic weight of 2. He is often said to have discovered "heavy water," for hydrogen combines with oxygen to make water. In helping him to his discovery the neutron once again came to the rescue. Ordinary hydrogen—${}_1H^1$—contains a proton and an electron; but heavy hydrogen—${}_1H^2$—has a nucleus made up of one proton and one neutron, with a single electron revolving around the pair. Both of these atoms are hydrogen, but they differ in atomic weight. Atoms which, like the two hydrogen atoms, belong to the same element but

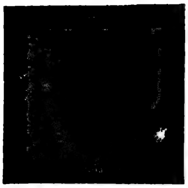


Official U. S. Navy Photograph

This is the beautiful but terrible sight that observers saw when an atomic bomb was set off under the water at Bikini. Ten million tons of water has formed a column over a mile high. Plutonium weighing some two-fifths the weight of a dime caused this explosion, in which the heat at the center reached 100,000,000° F.

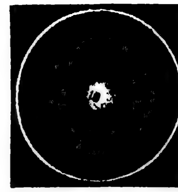
have a different atomic weight are called "isotopes" (ī′sŏ-tōp). Most of the known elements have isotopes. Chlorine (klō′rĭn), for example, has two isotopes: they are $_{17}Cl^{35}$ and $_{17}Cl^{37}$. Both atoms are chlorine, but the isotope having an atomic weight of 37 has two more neutrons in its nucleus than its lighter twin.

Uranium has three known isotopes. They are $_{92}U^{234}$, $_{92}U^{235}$, $_{92}U^{238}$. In any sample of uranium ore taken from the earth we find that most of the uranium—in fact, 99.2 percent—has an atomic weight of 238. But .7 percent has an atomic weight of 235, and a very tiny amount, .006 percent, has an atomic weight of 234.



This diagram shows an atom of hydrogen, with its single electron—a mere blur of energy—whirling around a single proton, the atom's nucleus, like a planet whirling around the sun.

In this atom a neutron—consisting of a closely united proton and electron—has been added to the nucleus of the hydrogen atom to make heavy hydrogen.



A proton and a neutron have been added to the nucleus of our atom, with the result that we now have a helium atom with two protons, two neutrons, and two electrons.

The scene of our story now shifts to Germany in the year 1939. Hahn and Strassman, two eminent scientists, were carrying on experiments in which they were bombarding a large number of elements with neutrons. Usually the neutrons bounced off the nucleus of the atoms and produced no effect. Sometimes, however, the neutrons would be captured by the nucleus of the atoms, and in this way new isotopes would be formed.

It was with particular interest that they looked forward to one experiment. What would happen if uranium—element number 92—were bombarded with neutrons? Would it behave like so many other elements and show no change? Or would it capture the neutron and form a new and hitherto undiscovered isotope?

When the experiment was performed the results were astounding. The uranium atom captured a neutron, and then its nucleus split into two separate masses. In this way two much lighter elements were produced—barium (bā'rĭ-ŭm), with 46 protons, and krypton (krĭp'tŏn), with 36 protons. But that was not all. Marksmanship among atoms is notoriously bad. Most of the space is empty. The chances of a direct hit are very small. Yet, even though they were striking only a dozen or so of the uranium atoms at the same instant, the experimenters noted a distinct rise in temperature inside the container in which the splitting, or "fission" (fĭsh'ŭn), of the uranium was taking place. The rise in temperature was beyond all expectation in view of the small amount of energy used in firing the neutron.

Then two other Germans—Lise Meitner (lē'zĕ mīt'nĕr), a distinguished woman scientist, and Otto Frisch (frĭsh)—added another important link in the chain of knowledge that scientists were working so hard to forge. They discovered that it was only in the isotope $_{92}U^{235}$ that a splitting of the nucleus—or "nuclear fission"—took place directly when the atom was struck by a neutron. This was the one fact which Copenhagen, Paris, Berlin, and Washington, in fact scientists all over the world, had wanted to know. Now they knew that when, in the process of capturing a neutron, the nucleus of $_{92}U^{235}$ was split, it let loose several other neutrons.

What Is a Chain Reaction?

Can you guess why this fact was so important? Imagine a row of firecrackers arranged so that the fuse of one is fastened around the center of the one before it. Lighting the fuse of one will set the whole line going. Of course, if there were any breaks in this line, the reaction would stop at that point. In other words, the firecrackers would cease to go off. The work of Meitner and Frisch clearly showed that if we could get pure $_{92}U^{235}$, free of the more common $_{92}U^{238}$, and if one neutron started to split one atom of $_{92}U^{235}$, the neutrons set free by that fission would in turn set off other atoms. Within a twinkling the whole mass would go up in a tremendous burst of energy. We call this process a "chain reaction." It is much like setting off a bunch of firecrackers by lighting just one.

During the war years the Allies as well

as the Axis powers worked feverishly to find methods of extracting large quantities of $_{92}U^{235}$ from $_{92}U^{238}$. The United States won the race, for not only did we have the money and the industrial resources to carry on the research, but also scientists, like Lise Meitner, who were driven out of Germany by the Nazis or out of Italy and other countries by fascist governments, all helped our own scientists toward the great result. Not alone were we able to get sufficient amounts of pure $_{92}U^{235}$ for our purposes, but in the process we developed ways of making other elements fissionable: thorium - 90 for instance, and protoactinium (prō'tō-ăk-tĭn'-ĭ-ŭm)—91. We even learned how to make certain elements artificially by bombarding $_{92}U^{238}$ with neutrons. In this way scientists created two new elements numbers 93, or neptunium (nĕp-tū'nĭ-ŭm), and 94, or plutonium (plōō-tō'nĭ-ŭm). Plutonium element number 94 - yields almost as much energy as $_{92}U^{235}$ when it is split by neutron bombardment.

Why an Atom Yields Us Energy

There is one important question that you probably have been asking yourself all along. Where does all this energy come from when an atom is split? In what form is it locked away inside that tiny particle?

The existence of nuclear energy was first pointed out by Dr. Albert Einstein in 1905. Curiously enough, it was not in a laboratory that the discovery was made. Taking the results of laboratory work, Dr. Einstein fitted them into a theory which made it possible for him to deal with them mathematically. This led him to propose his famous relativity theory, which predicted that a body in motion has a greater mass than a body at rest. Back into the laboratory went the theory for its test, and from the laboratory came the report that the theory held. Fast-moving electrons appeared to have greater mass than slow-moving ones. If, then, the energy of motion actually caused an increase in mass, could not the process be reversed? Could not a decrease in mass, or its complete destruction, give rise to energy? Again the laboratory went to work, but this time the answer did not come so quickly. How does one go about destroying matter? In 1905 scientists could only guess how this might be done. Nevertheless, Einstein maintained that if some day we should be able to destroy matter, to wipe it out completely and make it disappear from the face of the earth, vast amounts of energy would take its place. According to his calculations, if one pound of matter, just any matter, were completely destroyed, the transformation would yield enough energy to run a 100-watt bulb 13,000,000 years.

Rutherford's Discovery

In 1919 Sir Ernest Rutherford, an Englishman, came across an interesting fact which sent scientists scurrying back to the books to see what Einstein had said about the transformation of matter into energy. Rutherford had bombarded nitrogen atoms with the nuclei of helium atoms. When the reaction had taken place he found that there were atoms of hydrogen and oxygen present. Apparently when the nitrogen nucleus was hit with a helium nucleus, both masses fused for a moment and then split into a hydrogen and oxygen atom. Most puzzling, however, was the fact that the container in which the reaction occurred was much hotter than might be expected.

Changing Matter into Energy

Careful measurement revealed the source of the unexpected release of energy. It was shown that the sum of the weights of a nitrogen and helium atom is greater than the sum of the weight of a hydrogen and oxygen atom. Some matter, therefore, had disappeared and energy had taken its place.

The energy from nuclear fission comes from the destruction of matter. Let us see how this comes about when an atom of uranium, weighing 235 atomic mass units, is struck by a neutron weighing 1 atomic mass unit, making a total of 236 atomic mass units. Amazingly, the result of this bombardment is the formation of two lighter elements, barium and krypton; and at the same time that they are formed, a few neutrons are released. Now the heaviest known isotype of barium weighs 138 atomic mass units, and the heaviest known isotope of krypton

weighs 86 atomic mass units—a total of 224 a.m.u. If we assume that a neutron is also produced, we can write the reaction in the scientist's shorthand as follows:

$$_{92}U^{235} + _0N^1 = _{56}Ba^{138} + _{36}Kr^{86} + _0N^1.$$

We start with 236 a.m.u. and end with 225 a.m.u. In the process 11 a.m.u. have disappeared. They have been converted into energy. Eleven atomic mass units are certainly not much in terms of ounces or pounds. But when we keep in mind that each atom undergoing fission loses that mass, and that it requires vast numbers of atoms to make a piece of matter the size of a pinhead, we can see that the energy from a pound of uranium is great indeed. The explosion products of one pound of uranium 235 weigh .999 pounds. So only one-thousandth part of its mass is converted into energy. According to the Einstein mass-energy equation, the annihilation of one-thousandth of a pound of matter yields about 11,400,000 kilowatt-hours of energy. This is about the same amount of energy as can be had from 200,000 gallons of gasoline. That will explain why nuclear fission can furnish man energy beyond all imagining. When the first atomic bomb went off in New Mexico, it ushered in an age that we who live to-day are unable to forecast. We only know that it will be entirely different from all the ages that are past.

What Lies Just Ahead

Already we can see a few dim outlines of things near at hand. We are told that early in the 1950's atomic energy will be driving our ships and saving space that will be given to many tons of cargo. It is said that plans for using it in planes have reached the point at which engineers are actually at work on the blueprints from which the planes will be made.

For some time radioactive isotopes have been used in treating various diseases. When those tiny particles are taken into the body they travel about and reveal their presence wherever they go. Often a given isotope seems to be attracted to a special organ that is diseased—as, for instance, the isotopes of iodine will congregate in a diseased thyroid gland. Such isotopes are useful in various sciences. For example, they have helped explain photosynthesis in botany.

A little electronic device known as a "Geiger (gī′gẽr) counter" is the detective that reveals the presence of these isotopes and of any radioactive material—whether it be ores in the earth or substances that have become radioactive through contact with some other radioactive substance. For example, by way of experiment the United States Navy in the summer of 1946 exploded two atomic bombs in the lagoon at the island of Bikini (bē-kē′nē) in the Pacific. And afterward the Geiger counter showed that the water in the lagoon, the vessels that had been in the target area, and the rocks and soil the water had been splashed upon were highly radioactive.

The Puzzling Atom

Meanwhile, physicists are hard at work trying to find out more about the atom and its puzzling behavior. Their interest now is mainly directed toward the nucleus of the atom—toward what is known as "subnuclear fission"—and they are finding much that they are at a loss to account for. To carry on their work they use huge atom-smashing machines—the cyclotron and synchrotron. But more powerful still are the cosmic rays—those streams of electrically charged particles that reach the earth from somewhere in outer space. When protons in the cosmic rays pass through the atmosphere they break up the atoms they encounter and so give rise to brand-new particles—the powerful meson, of which there are at least five kinds, and the positron. Both mesons and positrons exist outside the atom's nucleus, and both have lives that last only some millionths of a second. As yet no theory that completely describes the relationship of protons, electrons, neutrons, and all these new particles has been found.

The Hydrogen Bomb

It was Dr. J. Robert Oppenheimer who directed the first trial of an atomic bomb (1945). Later that year he wrote a book in which he hinted that a much more powerful kind of bomb might be made, but that it could be used only for the destruction of large

targets, such as big cities. Nothing much was said about this until on January 31, 1950, President Truman announced that he had given orders to begin work on the hydrogen bomb. Most of the scientists believe that the attempt to build this superbomb will succeed. Let us see why they think so.

We have already learned how matter is changed into energy in the uranium and plutonium bombs. The annihilation of one thousandth of a pound of matter can yield enough energy to operate a desk lamp for thousands of years. In the uranium bomb matter is annihilated when the heavy uranium nuclei are split, or "fissioned," by neutrons. But matter can also be made to disappear when the nuclei of certain light elements are made to unite, or "fuse." This has been known for many years, but not until lately could anyone think of a possible way to get those light nuclei to fuse.

What Keeps the Sun Hot?

There is good reason to believe that most of the stars, including the sun, keep their energy going through the fusion of certain nuclei. For example, hydrogen atoms in the sun fuse to form helium atoms. Now, a helium nucleus contains two protons and two neutrons, or four atomic mass units. Yet the four hydrogen atoms out of which the single helium atom was fused had an atomic mass of about 4.03. Where did the .03 of atomic mass go? It was converted into energy—energy which reaches us as sunshine. It is very fortunate that the conversion of mass into energy in the stars and in the sun is a slow process. It takes a billion years for one percent of the hydrogen in the sun to be transformed into helium.

The fusion reactions can go on all the time in the centers of stars and of the sun because the temperature there is extremely high, perhaps 20,000,000° Centigrade. To get such a reaction on the earth, some way must be found to reach such temperatures. The uranium and plutonium bombs solve the problem. It is estimated that during the fraction of a second when an atomic bomb explodes, a temperature of about 50,000,000° Centigrade is reached. So it is possible that a uranium or plutonium bomb can be used as the "trigger" to start a fusion reaction between the nuclei of certain hydrogen atoms. The hydrogen atoms will form into helium atoms and some mass will disappear—to be transformed into energy.

Elements in a Hydrogen Bomb

A great deal of experimentation in fusion has been done in laboratories. It is found that the greatest amount of energy is liberated in the shortest time when the heavy isotopes of hydrogen ($_1H^2$ and $_1H^3$) are used, instead of ordinary hydrogen ($_1H^1$). $_1H^2$ is called deuterium and $_1H^3$ is known as tritium (trĭt'ĭ-ŭm). One atom of deuterium and one atom of tritium fuse to form one atom of helium, liberating a neutron and 17,000,000 electron-volts of energy. The reaction takes place in about one millionth of a second.

Dr. Harold Urey showed us how to make deuterium ($_1H^2$), or "heavy hydrogen." The Atomic Energy Commission, in charge of the government's program for atomic research, has found ways of making tritium ($_1H^3$). Since we already know how to make fission bombs with uranium ($_{92}U^{235}$) and plutonium ($_{94}Pu^{239}$), there is good reason to expect that a hydrogen bomb can be made.

What Is the "Critical Size"?

In a fission bomb neutrons are liberated from atoms in a lump of $_{92}U^{235}$ or $_{94}Pu^{239}$. Those neutrons liberate other neutrons and a chain reaction is started. The process goes on faster and faster until an atomic explosion results in less than a millionth of a second. But the lump of material must not be too small or too large. If it is too small there is no explosion at all; if it is larger than the "critical size," it will explode at once and be completely beyond control.

There is no such limitation on the hydrogen bomb. The more deuterium and tritium, the more powerful will be the bomb. A submarine can carry larger hydrogen bombs than an airplane, and a large hydrogen bomb will be able to wipe out whole cities. Such a source of power will have few, if any, peacetime uses, since we cannot control so vast an amount of energy liberated in less than a second.

Reading Unit No. 1

ELECTRONICS: MAN'S NEW SERVANT

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

The origins of the word electronics, 1-560
How to charge a rubber rod, 1-560
How to free electrons, 1-560
How freed electrons are put to work, 1-560
How certain metals make the electric eye possible, 1-561
The photoelectric tube, 1-561
How the electric eye makes our lives easier, 1-562-563
Things the phototube can do, 1-563
How we put sound into our movies, 1-563

Things to Think About

How much time could you save in a day if doors opened as you approached them?

How many things do you do in which you are helped by a vacuum tube?

Picture Hunt

How does energy move electrons? 1-560
How a diode receiver is set up, 1-562

Practical Applications

The electric eye acts as a safety device, 1-563
Metal can be inspected by electronics, 1-563

Summary Statement

It was once thought that electrons could not be removed from atoms, but now we know that we can make them work for men in a vast number of ways.

ELECTRONICS: MAN'S NEW SERVANT

How Electrons in Glass Houses Make Devices That Can Hear, See, Feel, Taste, Remember, Measure, Count, and Talk

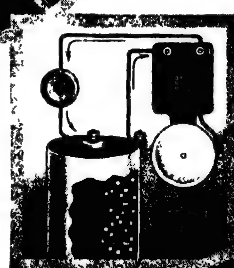
OUR word "electron" (ē-lĕk'trŏn) is not very old. It was first used by George Stoney in 1891. Stoney, like many other scientists of his day, had suspected that electrons were a part of all atoms. But he made one poor guess, for in his paper he stated that " . . . these charges, which it will be convenient to call electrons, cannot be removed from the atom."

Nothing could be further from the truth. Modern science has not only succeeded in ripping electrons from atoms but it has also put them to work for the good of mankind.

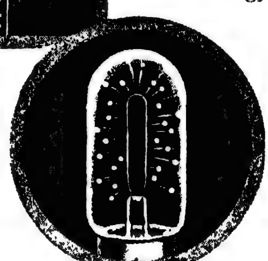
Any form of energy is able to release electrons from their atoms. Rub a piece of hard rubber against some wool or fur. To start with, the rubber has an equal number of protons (prō'tŏn), or positive electric particles, and electrons, or negative electric particles. As the rubbing is kept up, the mechanical energy of motion we have explained mechanical energy on other pages—rips loosely-held electrons from the wool or fur and deposits them on the hard rubber rod. The rubber rod now has more electrons than protons—that is, it has an excess of negatively charged electric particles. So we say that the rod is charged negatively.

Glass rubbed with silk lets loose electrons that gather on the silk. Having a lack of electrons and an excess of protons, the glass then carries a positive charge. A negatively charged hard-rubber rod will attract a positively charged glass rod, but two rods having the same charge will push each other away. Like charges repel each other; unlike charges attract each other.

Our pictures show how energy can move electrons. The boy has been rubbing his rubber rod with the fur he is holding. Electrons from the fur have moved into the rod and given it a negative charge, so that it will attract bits of paper.



Here it is chemicals inside the dry cell that transfer electrons to the cell's inner zinc coating. Connecting a wire between the zinc and the carbon rod in the cell makes the electrons flow from the zinc to the carbon. And if in their travels they pass through the bell, they will ring it for us.



Our sketch of a vacuum tube shows how electrons leave the filament when it is heated. In this case it is heat energy that moves the electrons.

Mechanical energy is only one of the means for removing electrons from atoms. In 1898 Thomas Edison found that electrons could be set free from the atoms of an incandescent lamp filament—the wire in an electric bulb—if the filament got hot enough. So heat energy gives us another means for removing electrons from atoms. Light, and chemical and electrical forms of energy, will accomplish the same purpose.

How can these freed electrons be put to work? Within the past fifty years science has discovered how to control electrons by means of the vacuum tube. A whole new branch of science called "electronics" (ē-lĕk-trŏn'ĭks) has been developed as a result. This science deals with the behavior of electrons, especially as they are made to pass through a gas or through a vacuum (văk'ū-ŭm)—that is, a space from which the air has been removed. The diode (dī'ōd) radio tube—described elsewhere in these books—

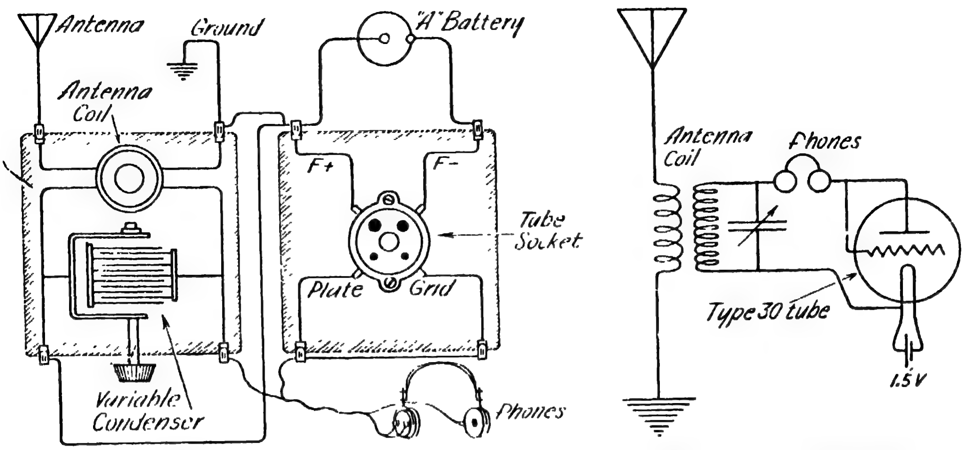
This picture was taken in one of the great Pittsburgh steel plants, where what is known as photoelectric "loop" control is used to operate the 10-horsepower pay-off-reel motor that is part of the machinery through which this sheet of metal is passing to be sheared. At the side of the picture is shown the source of light and also the photoelectric tubes massed in a bank twenty inches high.

was the first electronic tube in a family of tubes that now numbers well over a thousand different types. Using our knowledge of the principles of electronics, we can turn tiny marks on a strip of film into the voice of a popular screen star. A speech made in Washington may be heard in London in less than a fiftieth part of a second. By the use of electronic devices astronomers can measure the amount of matter in the empty spaces between stars, and mold spores can be killed in bread which has already been wrapped. It would take several volumes to tell about all the different ways in which freed electrons, controlled within the vacuum tube, can serve man's needs. We shall, however, want to learn something about the more important uses to which electronic tubes are put. Those processes are fast coming to form the very bases of our modern machine civilization.

Energy That Will Move Electrons

We have already pointed out that energy in different forms can rip electrons out of atoms of matter. The mechanical energy of motion can take electrons from one substance and give them to another. The right kind of chemicals, properly arranged, can make a stream of electrons move through a wire. Heat energy can cause electrons to evaporate out of a hot filament. How can light energy be used to knock electrons out of atoms?

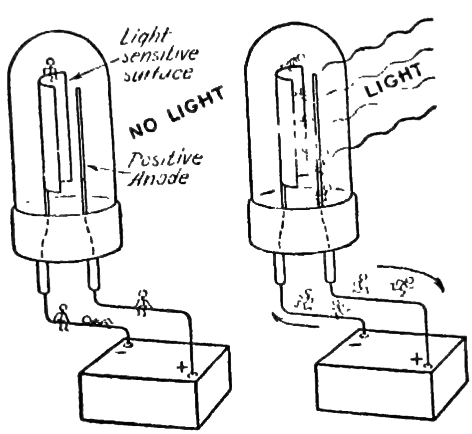
Experiments show that when light falls on metal surfaces electrons are given off just as if the metal were heated. Certain metals like cesium (sē'zĭ-ŭm), potassium (pŏ-tăs'ĭ-ŭm), and sodium are very sensitive to light and eject electrons readily when they are illuminated. It is these facts that we make use of in the photoelectric (fō'to ē-lĕk'-trĭk) tube—the "electronic eye." Such a tube is built very much like a two-element radio tube. Instead of a filament, the phototube contains a broad, curved metal plate coated with caesium or some other material that is sensitive to light. A wire connects the plate with a terminal outside the glass envelope, the covering of the tube. Within the tube, a short distance from the sensitive plate, is a metal rod which is also connected with a terminal outside the tube. The photoelectric tube has two contacts. In use, a high-voltage direct current, often supplied by a B-battery, is connected across the tube. Its negative terminal is connected with the light-sensitive plate—called the cathode



You can build a diode receiver it you care to. Use a type-30 tube and compare the picture diagram, lett, with the symbol diagram, right. The grid of the tube has been tied to the plate, making it inoperative.

(kăth′ōd)—and its positive terminal is connected with the rod—or anode (ăn′ōd). While the tube remains in the dark there is no flow of electrons across the space between the light-sensitive plate and the rod. But if light falls on the caesium coating of the cathode, electrons are knocked out. They are then attracted to the nearby positively-charged rod, and so a procession of electrons starts from the plate to the rod. As long as the light continues to shine on the phototube, a current similar to the plate current in a vacuum tube keeps on flowing through the photoelectric tube.

In many public buildings there are doors which seem to open of themselves as a person approaches. It is the phototube, or "electric eye," which operates the mechanism. The door itself is moved by an electric motor which can run in either direction, thus opening or closing the door. There is a reversing switch which, when thrown one way, opens the door and if thrown the other way, reverses the direction of the motor so as to close the door. If there were an attendant on duty to operate the switch he could open and close the door as people pass through, but the phototube can do this job just as well.



The photoelectric tube at the left is in the dark. Since no light is falling on its light-sensitive metal plate, electrons cannot leave the plate and there is therefore a gap in the circuit of the high-voltage battery with which the tube is connected. But suddenly light strikes the tube, and now, as the sketch on the left shows, electrons begin to leave the plate and go to the positively-charged rod. From there they go to the positive terminal ot the battery and an electric current is set up through the battery and the tube.

As a person approaches the door his body cuts off a beam of light which is shining steadily on a phototube. When nothing cuts off that beam, the tiny current which it causes to flow through the circuit of the phototube passes through an electromagnet. This electromagnet in turn holds the reversing switch of the motor in the closing position. But

when the beam of light is interrupted by someone's approach, the electromagnet is no longer energized by the tiny photoelectric current. So it releases the switch. The switch then snaps over to the opening position, and the door opens. When the tube is again illuminated, after the person has passed through the door, the current flows through the phototube, the sensitive electromagnet draws back the switch, and the motor closes the door. Note that the energy for moving the door comes from the house power line. This power, however, is under the control of the phototube.

Industry and research have found many uses for the phototube. The electric eye can be made to count passing articles faster than the human eye. It can protect workers on dangerous machines; fill bottles to the proper level; compare colors; inspect sheets of metal gliding swiftly from the rolls, spot pinhole defects, and mark them for later discard; turn on highway lights as the sky darkens and turn them off at dawn. The phototube has come to be one of the most highly valued members of the electronic tube family.

Your parents can probably tell you how the old lifeless, silent motion pictures compared with the modern brilliant productions which sound has made possible in the "movies." The addition of sound to motion pictures was a result of the development of the phototube.

The method by which the sound is recorded on the outside edge of the film is very simple. As you already know, a current of electricity in a wire produces a magnetic field around the wire. If two wires carrying electric current in the same direction are placed side by side, their magnetic fields will cause the two wires to be attracted toward each other. If the current through one of the wires is varied, the amount of attraction between the wires will also vary.

In the sound-recording device used for making a film a beam of light is made to shine between two wires and to fall upon the outside edge of the photographic film. The sound to be recorded is first picked up in an ordinary microphone. The microphone turns this sound into pulsating electric currents—on other pages we have explained how this is done. After it is amplified, the pulsating electric current is sent into the two wires already mentioned. The attraction of the wires for each other will be varied in the way we have explained above, and the space between the wires will therefore vary in accordance with the sound. If the film is now made to move past this varying slit between the wires while the light shines through the slit, the film when developed will show strips of varying intensity of blackness all along the edge of the film. The variations in blackness will follow exactly the vibrations of the sound originally picked up by the microphone.

To "read" the sound from the film we use a phototube. The sound track—that is, the shaded strip along the edge of the film—is pulled between the phototube and a light source. When dark portions in the strip come between the tube and the light, only a small amount of light can fall on the phototube, and therefore only a little current passes through the tube. As lighter portions of the track pass the phototube, the increased illumination of the tube causes an increased flow of current inside the tube. A varying current is thus set up through the phototube. This current varies in accordance with the variations in the blackness of the sound track on the film and consequently it varies in accordance with the sound originally made in the studio. Of course the sound current set up in the phototube is weak and must be amplified by vacuum tubes. After amplification it is sent into a loud speaker which can fill the theater with sound.

ELECTRONICS

Reading Unit No. 2

A WAY TO EXTEND OUR SENSE OF TOUCH

Note: For basic information not found on this page, consult the general Index, Vol. 15.

For statistical and current facts, consult the Richards Year Book Index.

Interesting Facts Explained

How a problem of television became the key to radar, 1–565
What "radar" means, 1–565
How microwaves are made and used, 1–565
What an echo has to do with radar, 1–565
How distance is measured by radar, 1–565-566
What the pip means on the radar "scope," 1–566
How radar gives the direction of a distant object, 1–566
The applications of radar in peacetime, 1–566-567

Things to Think About

How can a ship come into a crowded harbor in a thick fog?
How can radar prevent airplane crashes and make flying safer than ever before

Picture Hunt

What a magnetron looks like, 1–565
What a radar "scope" looks like, 1–566

Related Material

How television, radar's first cousin, works, 10–123-126
Other ways in which we use electronics, 1–559-563

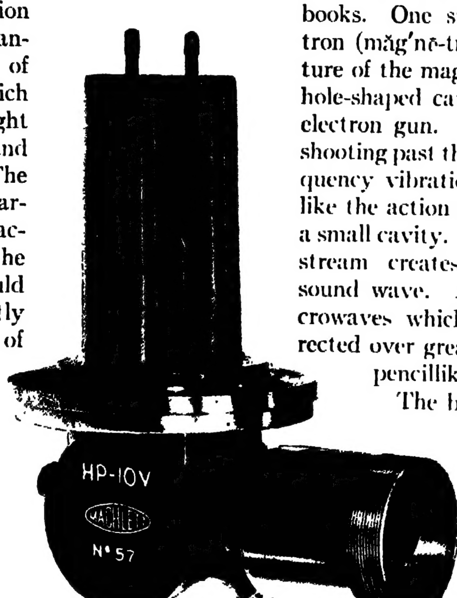
Summary Statement

The problem of "ghosts" haunted early experimenters in television, but they have made possible radar—an invaluable weapon in warfare, which could warn our ships, our shores, and our planes of the enemy's approach. Now we have radar in peacetime, a device which protects mariners and aviators from harm.

A WAY TO EXTEND OUR SENSE OF TOUCH

How Radar Helps the Aviator to See through Clouds and Will Warn of the Approach of an Enemy Plane

Many problems plagued the early experimenters in television—an amazing invention which we have described on other pages—but the one problem they were most eager to overcome was the appearance of "ghost" images on the screen of the television receiver. The "ghosts" were caused by reflections of part of the television wave from high buildings and other structures in the vicinity. As the television wave swept past the antenna, a small portion of that part of it which missed the antenna might strike a distant object and be reflected back. The reflected signal would arrive at the antenna a fraction of a second after the main signal and would produce an image slightly out of register—or "out of line"—with the first image. One enterprising experimenter found that he could easily tell how far away the reflecting building or other object was from his receiver by observing the amount by which the ghost image on the screen was displaced from the main image.



This is a high-powered microwave magnetron—one of the kind that were developed during the war to help in the various uses to which radar was put for our national defense. This particular tube is for "pulsed operation"—that is, the power is on for about a millionth of a second and is off for a thousandth of a second. Its pulsed output is 205,000,000 watts.

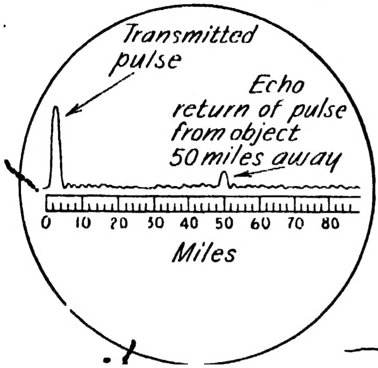
It took a war to turn a problem into an answer. For when we sought for a method of detecting and determining the direction of enemy aircraft, the answer was found in the television ghost. Radar (rā′-där)—from the words "*ra*dio *d*etection *a*nd *r*anging"—is a first cousin to television.

Radar uses even higher frequencies than television. Such high-frequency waves behave very much like light waves. They do not follow the curvature of the earth and they are stopped and reflected by solid objects. The frequency of radar waves is so great that their wave length is scarcely more than an inch. These ultra-short waves are sometimes called "microwaves."

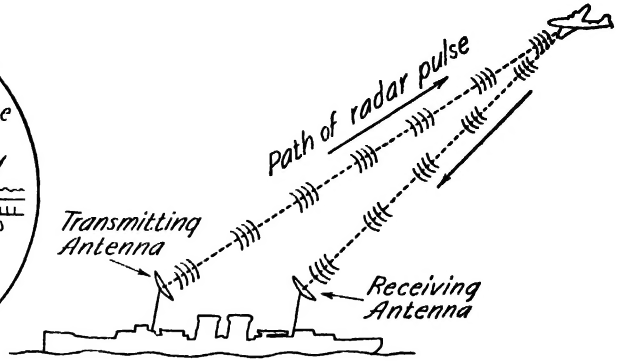
Microwaves are made in special electronic tubes. We have described the working of an electronic tube on other pages of these books. One such tube is the magnetron (măg′nē-trŏn). An important feature of the magnetron is a series of keyhole-shaped cavities which surround an electron gun. The stream of electrons shooting past these holes sets up high-frequency vibrations. This is very much like the action of air when blown across a small cavity. As we know, such an air stream creates a shrill, high-pitched sound wave. Magnetrons produce microwaves which can be accurately directed over great distances in a narrow, pencillike beam.

The basic principle of radar is the same as that of an echo. The radar transmitter sends out short, powerful bursts of microwaves. These bursts of energy travel out into space with the speed of light, about 186,218 miles a second. The timing of the signals is such that one impulse has traveled out, let us say, 200 miles before the next burst is transmitted.

Located near the radar transmitter is the radar receiver. Since it is so close to the transmitter, the receiver picks up each radar impulse as it is transmitted. In addition, however, the receiver is also sensitive to any of the transmitter impulses which may have been reflected from nearby objects. An important part of the receiver is a kinescope



This diagram shows the kind of line traced on the kinescope screen in a radar receiver. The tall "pip," or peak, at the left is made by the transmitted wave when it is sent. The smaller pip in the center is an echo from an object fifty miles away.



A ship carrying radar equipment is able to detect an airplane at a considerable distance. Impulses are sent out by a transmitting antenna. When they reach the plane they are reflected back to the ship—to be picked up by the ship's receiving antenna.

(kĭn'ē-skōp) tube very similar to the ones used in television receivers. The electron beam in the kinescope is made to trace out a single horizontal line on a fluorescent (flōō'-ō-rĕs'ĕnt) screen—that is, a screen that emits light of its own under certain kinds of rays. The electron beam traces out its line by being pulled across, returned immediately, and then pulled across again. The rate of sweeping across is synchronized (sĭn'krō-nīz)—or timed to fit—with the pulses of the transmitter. As the transmitter sends out a burst of microwaves the electron pencil starts the line on the kinescope screen. As the pulse travels out, the flying spot sweeps across the screen. By the time the pulse has traveled out the required 200 miles, a line has been traced completely across. Just as the transmitter emits a second burst the spot is once again at the starting point and moves across the screen in as long a time as it takes the second burst to cover 200 miles.

Any signal—that is, any radar wave—entering the receiver causes the moving spot of light on the kinescope screen to be pulled vertically upward. At the beginning of the line, just as the spot starts to move, a peak, or "pip," appears. This is caused by the transmitted wave. If, as the spot moves across, a reflected wave is received from an object 50 miles away, a weak "pip," or bump, will appear at the center of the line. Remember that an echo must make a round trip, so that a "pip" at the end of the line represents an object 100 miles away but means that the wave has made a total trip of 200 miles. By rotating in unison the antennas of both the transmitter and receiver, a complete circle or even the entire sky can be scanned. In this way we can determine the distance of objects and also their direction. This principle gave rise to Shoran, a system for measuring the distance between two points and so mapping a region.

With the end of the war radar was applied to peacetime activities. It will certainly do away with much of the uncertainty and risk in air travel. Controllers at ground radar sets at airports along the coast can unfailingly guide transports home in any weather. Radar mounted in a plane can tell the pilot his exact height above the surface of the earth. With certain modifications the pilot can view on his radar screen an exact picture of the earth's surface below him, even though fog hides the ground.

The applications of radar are many. In 1942, while a radar set was being tested, "echoes" in the form of vague, fluffy images appeared on the screen. These images could not have been caused by planes or other solid objects. Upon investigation it was found that rain-filled thunder clouds caused the echoes. Then and there, radar provided the weather man with a tool for de-

Photo by U.S. Army Signal Corps

An echo from the moon! It sounds fantastic. Yet that is what we got when radar signals aimed at the moon were sent out from the radar antenna you see above. It was the first time man had ever had any signal from the vast reaches of empty space. But radar is being put to much more important uses. For example, by "G.C.A."—or "ground-controlled approach"—it will prevent accidents in the landing of planes.

tecting on-coming storms much sooner than he could by any other method.

Using high-power radar pulses, scientists beamed radar waves at the rising moon on January 10, 1946, and in 2.4 seconds received a feeble response. The waves which were hurled from the earth and echoed from the moon made a round trip of about 470,000 miles. These experiments proved that radio waves of very high frequency can pierce the electrically charged layer that lies above the stratosphere. Interesting data on the earth's atmosphere and perhaps the atmosphere and surface of nearby planets will come from these investigations.

Microwaves are not used for radar alone. With the development of new tubes similar to the magnetron, very powerful high-frequency radio currents can be generated. Engineers noted that materials near such high-frequency transmitters grew hot if the radio waves surged through them. Basing experiments on this fact, scientists found that if metallic objects were placed at the center of a coil through which high-frequency radio waves were flowing, the molecules of the object danced about and caused the metal to grow hot. Non-conductors could be heated by sandwiching them between two metal plates connected with a high-frequency transmitter.

In a matter of seconds, then, powerful microwaves can be used to bake to white heat the metal insides of newly manufactured vacuum tubes without even warming the glass envelope. Slowed down, microwaves can be used to vulcanize rubber, kill weevils in grain elevators, make better plywood, and even cook "hot dogs." Induction heating, as heating by microwaves is called, can cut costs, provide cleaner, more pleasant working conditions, and make possible a whole host of new products, which can give to us all an easier, more abundant life.